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Doctoral Dissertation
Doctoral Program in Energetics (29th Cycle)

Nearly Zero Energy multi-functional Buildings

Energy and Economic evaluations

By

Tiziana Buso

******

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Politecnico di Torino
2017

Declaration

I hereby declare that the contents and organization of this dissertation constitute my own original work and do not compromise in any way the rights of third parties, including those relating to the security of personal data.

Tiziana Buso

2017

This dissertation is presented in partial fulfillment of the requirements for **Ph.D. degree** in the Graduate School of Politecnico di Torino (ScuDo).

Dedicated to my family,
who still wonders what I have been doing all day for the past 3 years.

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Abstract

Building energy renovation is one of the pillars upon which the 2050 European low-carbon goals are based. Simultaneously, building energy renovation is widely recognized as the trump card for the new start of European economy. However, at present the renovation rate of the existing building is very low throughout Europe (approximately 1%) and investments in high performing buildings are generally mistrusted by stakeholders, due to their high capital costs.

In this context, this PhD thesis dedicated its efforts to investigate from the energy and financial perspective the consequences of buildings renovation in the European scene. Particularly, the research boundaries were delineated by focusing on non-residential, multi-functional buildings, that are nowadays poorly studied due to their heterogeneous nature.

In this view, the thesis' contributions were addressed at three levels:

a) multi-functional buildings as archetypes to input in energy models for long-term energy analysis;
b) multi-functional buildings used to test the financial viability of energy efficiency projects, in view of reaching the nearly Zero Energy performance level. As these analyses necessarily require case studies, the attention was directed towards a specific type of multi-functional buildings, hotels;
c) multi-functional buildings as test-bed to assess the impact of co-benefits on the financial performances of energy efficiency projects. Once again, hotel buildings were selected for the development of the detailed analyses.

To include archetypes of multi-functional buildings in bottom-up building energy models, a new modelling method was proposed. The method provides a rationale for the classification of energy end-uses into typical and extra, so that the modeling problem is simplified and a coherent use of well-established Reference Buildings modelling methods is allowed.

Then, the focus of the research was narrowed to the hotel sector, which was found to lack of reliable energy performance benchmarks and effective performance-based greens labels. Case study buildings were object of energy and financial evaluations. On one side, real hotels were analyzed to test the application of the EU imposed cost-optimal methodology as a support tool to guide private investors' investment decisions. On the other side, an Italian Reference Hotel was modelled and the cost-optimal methodology was applied to investigate the existing energy and financial gaps between cost-optimal and Nearly Zero Energy performance level in Italy. From both perspectives, findings converged to similar conclusions: high performing retrofit are not financially viable, if avoided energy costs are the only operational benefits accounted for.

Starting from these outcomes, the thesis investigated how valuation procedures could be exploited to make NZEB retrofit solutions appealing for private investors. Based on a literature review of the co-benefits of energy efficiency projects, 2 different strategies were pursued and tested on the Italian Reference Hotel. The first approach proposed to monetize co-benefits of energy efficiency interventions based on literature and to include them in the well-established cost-optimal methodology. Results highlighted that co-benefits related to the market appreciation of a retrofitted hotel can drastically change the perception of the financial convenience of an ambitious retrofit project. In the latter strategy, the issue of monetizing non-energy benefits was faced directly: a technique to value non-market goods was applied to monetize comfort. Findings proved that hotels guests' willingness to pay for comfortable indoor conditions is higher than the hoteliers' extra costs for providing them. Due to the context-dependent nature of co-benefits, the findings of the 2 applications do not represent generally applicable quantitative benchmarks. Nonetheless, they confirm the leading role that literature attribute to co-benefits in the success of energy efficiency projects.

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PART I

Chapter 1

1. Introduction

1.1 The big picture

Building energy renovation is one of the pillars upon which the 2050 European low-carbon goals are based (European Commission 2011). Simultaneously, building energy renovation is widely recognized as the trump card for the new start of European economy (Saheb et al. 2015). Combining successful financial and environmental performances is going to be the new mantra for the real estate sector (Bosteels & Sweatman 2016).

However, many pending issues have the potential to dim the bright future envisaged for the European building stock. For instance, at the policy level the decarbonization of the built environment requires effective and robust long-term energy strategies, which in turn ask for reliable building stock models for the development of their analyses. However, these models are still object of scientific debate. At the market level, instead, the economic and financial advantages of low-energy/low-carbon buildings are out of the interests of most the small-medium real-estate stakeholders, who generally mistrust high-performing solutions due to their sizeable capital costs (Dwaikat & Ali 2016). In this context, the PhD thesis dedicated its efforts to investigate from the energy and economic perspective the potentialities of buildings retrofits in the European context.

These ambitious purposes had to be re-sized to fit into the PhD research path. The focus of the research was therefore narrowed to multi-functional buildings, which are a complex, energy-intensive trans-category of non-residential buildings. These buildings are interesting object of study in view of contributing to unravel the issues previously mentioned, as they are, at once, almost ignored in energy efficiency plans and the most sensitive buildings to the market success of investments.

In this view, the thesis' contributions were addressed at two different levels:

a) multi-functional buildings as archetypes to input in energy models for long-term energy analysis;
b) multi-functional buildings used to test the financial viability of energy efficiency projects. As these analyses necessarily require case studies, the attention was directed towards a specific type of multi-functional buildings, hotels. These accommodation structures well exemplify the heterogenous type of activities that may be in place under the same roof and the strong link between environmental performances and business success.

1.2 Theoretical background

The ultimate goal of the research was to contribute to a more realistic depiction of the non-residential sector in Europe in order to support decision makers in defining effective strategies to improve the energy performance of the building stock. To ensure the relevance of findings, the investigations built upon concepts and methods that are well-acknowledged by EU policy-makers:

- Cost-optimal methodology;
- Nearly Zero Energy Building concept.

1.2.1 Cost-optimal methodology

In 2010, the recast of the Energy Performance of Buildings Directive (European Parliament 2010), introduced in Europe the concept of cost-optimality as a way to reasonably tighten the minimum building energy requirements in place at that time. By implementing this method for the definition of mandatory energy performance levels, the need to make the targets set with the previous EPBD (European Parliament 2002) more ambitious is combined with considerations about the financial and economic convenience of the future targets. Specifically, the cost-optimal level of energy performance is defined in Article 2 of the EPBD recast as "the energy performance level which leads to the lowest cost during the estimated economic lifecycle" and in Article 4 it is stated that EU Member States (MSs) have to "assure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels". Detailed information about the comparative methodology framework to identify cost-optimal levels were released in 2012, with the Commissions Delegated Regulation 244/2012 and its accompanying guidelines (European Commission 2012a; European Commission 2012b).

These documents detail how Member States should implement cost-optimal methodology at the national level. As summarized in Figure 1-1, MSs must:

- establish at least nine reference buildings – one for new buildings and two for existing buildings subject to major renovation, for single-family, multi-family, and office buildings respectively. Additional reference buildings must be defined in case energy performance requirements are in place for different building categories (i.e. the other building categories listed in EPBD recast: educational buildings, hospitals, hotels and restaurants, sports facilities, wholesale and retail trade services buildings, and other types of energy-consuming buildings);
- define energy efficiency measures (EEMs) and their combination in packages of EEMs, to be applied to these reference buildings. At least ten configurations must be tested on each Reference Building;
- assess the primary and final energy uses of the reference buildings before and after the implementation of EEMs and packages of EEMs;
- calculate the global cost of the building after energy efficiency measures are implemented, by applying the principles outlined in the comparative methodology framework;
- derive the cost-optimal level of energy performance and compare it to the minimum energy performance requirements in force. If this calculation demonstrated a deviation from the requirements larger than 15%, the MS should modify the requirements.

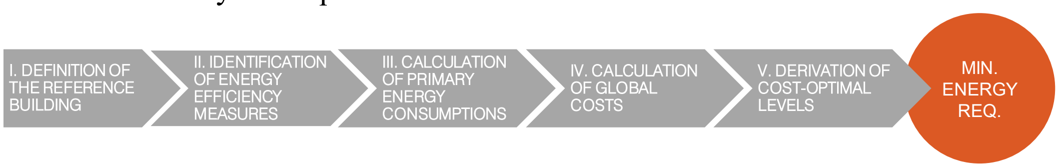


Figure 1-1: Steps of the cost-optimal methodology

In this thesis, the cost-optimal methodology was the starting point to propose a method to model archetypes of multi-functional buildings. The same methodology was then fully exploited to investigate the most financially convenient retrofit options for fictional and real hotel buildings. The selected fictional building is a newly proposed Italian reference hotel, to which cost-optimal analysis was applied to spot the energy and financial gap between cost-optimal and Nearly Zero Energy performance level. This application is in line with the EU guidelines, which presented cost-optimal methodology as a tool to drive national legislation towards reachable energy performance requirements. In the analysis of real hotels, instead, cost-optimal methodology was proposed as a preliminary support tool to guide hoteliers' investment decisions.

Finally, the cost-optimal methodology was also the starting point for the proposal of different items to be accounted for in the financial evaluation. Specifically, it was proposed to include co-benefits related to energy efficiency projects in the traditional global cost formula.

1.2.2 Nearly Zero Energy Building concept

It is again the recast of Energy Performance of Building Directive (European Parliament 2010) that introduced the concept of Nearly Zero Energy Building (NZEB). In Article 9 of the EPBD recast, the European Commission set a new challenging target for Member States, asking them to ensure that by "by 31 December 2020 all new buildings are nearly zero energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings". MSs shall furthermore "draw up national plans for increasing the number of nearly zero-energy buildings" and "following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings".

In Article 2 of the same directive nearly zero energy buildings are generally described as high-performing buildings, whose very low energy use is covered "to a very significant extent" by energy for renewable energy sources. No limit value was imposed.

Thus, while the NZEB goal is common for all Member States, the approaches and calculation methods to practically reach it are left as a prerogative of each Country, acknowledging the variety of climatic, cultural and economic conditions throughout Europe. However, the combined implementation of Article 9 (NZEB) and article 4 (Cost-optimal minimum energy requirements) will entail, in 2019 for public buildings and in 2021 for private buildings, the convergence between the cost-optimal calculations and the definition of NZEBs. To this purpose, the Commission Delegated Regulation No. 244/2012 (European Commission 2012a) states that the calculation of costs for establishing NZEBs should be included as a variant in the national calculation exercises to identify the cost-optimal levels for new buildings. Figure 1-2 conceptually depicts the envisaged shift in the relation between minimum and NZEB energy performance requirements.

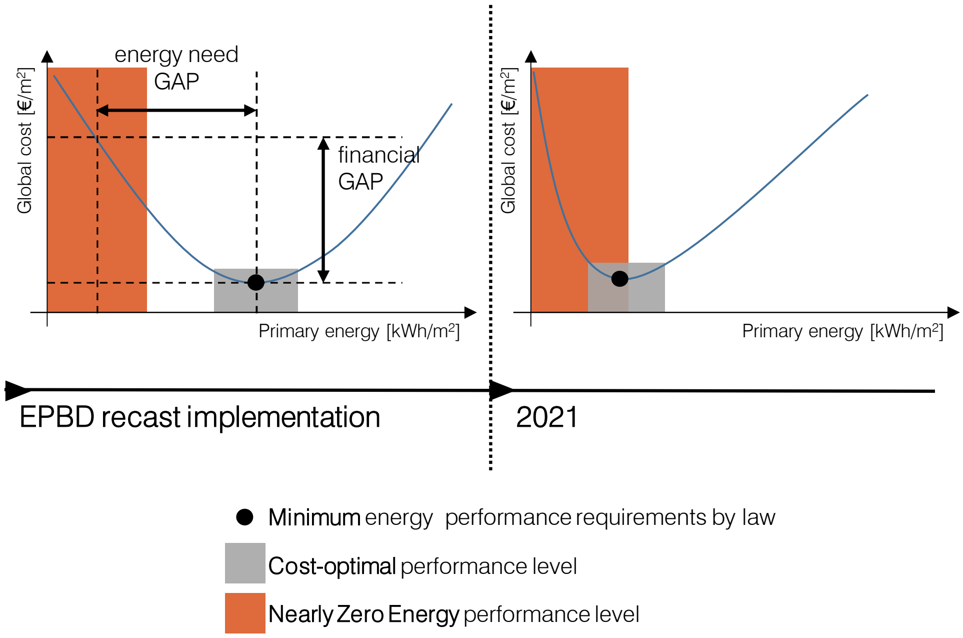


Figure 1-2: Minimum requirements, NZEB and cost-optimal levels of energy performance as envisaged by the EPBD recast.

In the context of the PhD research, specific object of analysis was the Italian interpretation of the Nearly Zero Energy Building concept. The country-specific focus is justified by the interest of the authors in investigating the currently existing gap between cost-optimal and nearly zero energy performances of Italian hotels.

1.3 Research questions of the thesis

The PhD candidate identified four research questions that need to be addressed in order to contribute to an effective energy performance upgrade of the non-residential building stock:

1) How to include non-residential buildings in buildings energy models?
2) Is the accommodation sector effectively reducing its energy use?
3) Is NZEB level cost-optimal for multi-functional buildings?
4) How to include co-benefits in valuation procedures?

1.3.1 How to include non-residential buildings in buildings energy models?

Building stock models for long term energy analysis are nowadays a hot topic among researchers, due to the binding low-carbon goals globally imposed. Indeed, robust energy models are powerful tools to test possible development scenarios for the buildings sector itself and for the relations among buildings and other major economic activities. However, most of these models focus on the residential sector only, for which more information is available. The energy use patterns and the features of the heterogenous non-residential building stock are generally described only in aggregate terms, which are not relevant for the inclusion of non-residential buildings in detailed energy models.

1.3.2 Is the accommodation sector effectively reducing its energy use?

The focus of this question on the accommodation sector is justified by the fact that accommodation structures well exemplify energy-intensive non-residential, multi-functional buildings. The accomplishment of the low carbon goals passes through the tourism sector as well, as testified by the general attention given to sustainable tourism in recent years. However, the promotion of environmental friendly tourism activities is not supported by reliable data on the energy use of the hotel sector. While hotel related green labels flourish, the knowledge of the energy use patterns of European hotels remains poor and scattered.

1.3.3 Is NZEB level cost-optimal for multi-functional buildings?

Framing the interest for the energy performance of non-residential, multi-functional buildings in the current legislative framework (i.e. the EPBD recast) entails the investigation of cost-optimal levels of energy performance for these buildings. Indeed, at present, they are almost ignored in national legislations. The financial and technical feasibility of the NZEB target should also be investigated, to spot potential barriers for the successful fulfilment of the NZEB target for the building stock as a whole. As the NZEB definition varies from Country to Country, Italy was the selected target Country to investigate the possible energy and financial gaps between cost-optimal and NZEB level.

1.3.4 How to include co-benefits in valuation procedures?

This question builds upon several pieces of research that promote energy efficiency projects as responsible of a wide range of non-energy benefits, that drastically improve the financial and economic performance of these interventions. However, the practical inclusion of these co-benefits in the valuation discipline is still a pending issue, due to their highly context-dependent nature, and to the non-monetary nature of most of them.

Each research question was object of a dedicated chapter of this dissertation, as described in the following section.

1.4 Thesis outline

Bowed to the Italian academic tradition, Part I of this PhD dissertation is a monograph that presents in a structured form the PhD candidate’s researches gravitating around the issue of energy and economic evaluations for the retrofit of existing multi-functional buildings. However, most of the PhD research outcomes were also object of international scientific publications, that trace the same research path. These publications are enclosed in Part II of the thesis. In both Parts, the dissertation contents are organized to contextualize and answer to each of the 4 research questions listed above, following a logical development.

The contents of Part I are organized as follows:

- Chapter 2 is dedicated to the description of the objects of evaluation, i.e. multi-functional buildings, in view of their inclusion in building stock energy models. In line with the archetype-based modelling approach, exploited in major EU studies on buildings renovation pathways, a method to define Reference multi-functional Buildings was presented.

- Chapter 3 is devoted to critically analyze the environmental and energy performances of the hotel sector based on the available literature, interviews and certification tools (i.e. green labels).

- Chapter 4 reports how the cost-optimal methodology was applied to evaluate retrofit options for hotel buildings, aiming at testing if the nearly Zero Energy performance level is feasible and convenient. In this regard, two different lines were followed during the research activities:
  a) cost-optimal methodology applied to an Italian Reference Hotel (RH) and addressed to policymakers. The Reference Hotel model is an original result of the research. It was created by applying the multi-functional building modelling approach, presented in Chapter 2. Several retrofit options were tested for the RH in order to satisfy the recently defined Italian NZEB requirements. The cost-optimal methodology was here applied to spot the current gap between the cost-optimal and the NZEB level of energy performance in hotel buildings.
  b) cost-optimal methodology applied to case studies of existing hotel buildings. The goal of these calculations was to provide the involved hoteliers with cost-optimal retrofit solutions for their businesses, towards the fulfilment of Nearly Zero Energy requirements.

- Chapter 5 embraces the statement declaring that traditional evaluation method fail to reap less tangible - but equally important – financial and economic co-benefits. Based on this hypothesis, the final step of this PhD research was dedicated to proposing solutions to include co-benefits in the evaluation of energy efficiency interventions. Using the Reference Hotel as starting point for the analysis, two different strategies were proposed:
  a) Inclusion of co-benefits in the traditional EU-recommended global cost formula. Based on literature review, a series of co-benefits regarding energy efficiency interventions were identified, quantified and included in the financial calculations, resulting in the proposal of a global cost-benefit formula.
  b) As the monetization of co-benefits is a complex issue, a further development of the investigation led to embrace an economic approach to the problem. Particularly, the Contingent Valuation Method was applied to monetize comfortable indoor conditions in hotels guestrooms. The monetized co-benefits were compared with the operational expenses necessary to reach the optimal comfort conditions, quantified through simulations. This approach to the valuation of comfort represents a novelty in the field, as comfort co-benefits are typically taken into account with an engineering approach only.

Figure 1-3 schematically recalls this structure.

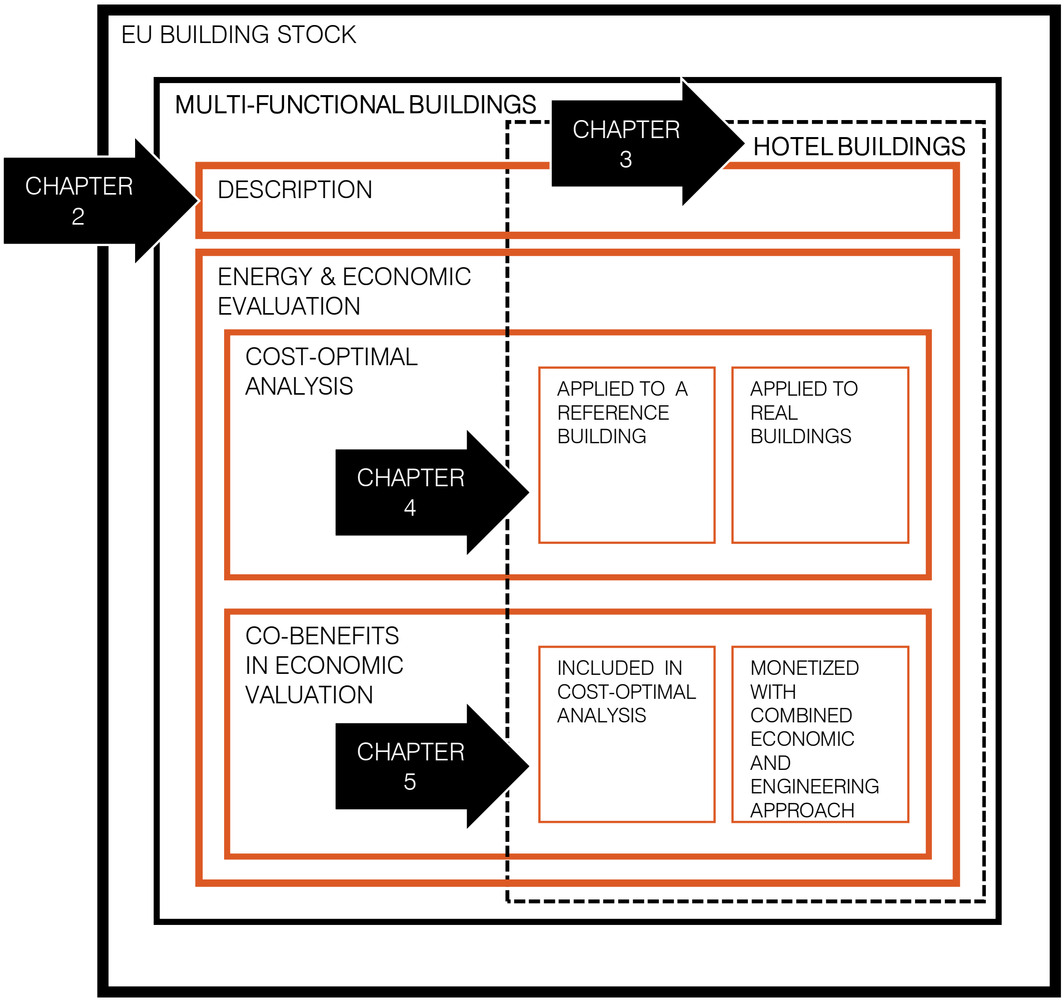


Figure 1-3: schematic summary of Part I of the PhD thesis.

To guide the reader through the text, each chapter is introduced by a schematic summary. It recalls the background information which led to formulate the research question, reports the research question and summarizes the PhD proposals to address the problem. In the scheme, reference is made to the contents presented in the dissertation and to the published papers proposing the corresponding contents.

The author's papers referenced in Part I are enclosed to the dissertation in Part II. Indeed, Part II is a collection of publications organized based on the investigated research questions. Table 1-1 lists the selected publications and the research questions they relate to, in order of appearance in the dissertation.

Table 1-1: List of research papers relevant to the PhD dissertation

RESEARCH QUESTION	PAPER	TITLE
How to include non-residential buildings in buildings energy models?	Paper I	Kurnitski, J., Buso, T., Corgnati, S.P., Derjanecz, A., Litiu, A., 2014. NZEB definitions in Europe. REHVA Journal, (2), pp. 6–9
	Paper II	Buso, T. and Corgnati, S.P., 2017. A customized modelling approach for multi-functional buildings – Application to an Italian Reference Hotel. Applied Energy, 190, pp. 1302–1315.
Is the accommodation sector effectively reducing its energy use?	Paper III	Buso, T., Corgnati, S.P., Kurnistki, J., 2014. An existing best practice of nearly Zero Energy Hotel. REHVA Journal, (3), pp. 61–65.
	Paper IV	Buso, T., Corgnati, S.P., Derjanecz, A., Kurnitski, J., Litiu, A., 2014. Nearly zero energy hotels. REHVA Journal, (1), pp. 7–11.
Is NZEB level cost-optimal for multi-functional buildings?	Paper V	Buso, T., Corgnati, S.P., Kurnitski, J., 2015. Defining the Reference Hotel – toward nearly Zero Energy Hotels design. In Climamed2015 - proceedings of 8th Mediterranean Congress of Heating Ventilation and Air-Conditioning. Juan-les-Pins.
	Paper VI	Buso, T. Becchio, C., Corgnati, S.P., 2017. NZEB, cost- and comfort-optimal retrofit solutions for an Italian Reference Hotel, Proceedings of 50th AiCARR International Conference – Beyond NZEB buildings, Matera.
	Paper VII	Buso, T., Carbone, M., Corgnati, S.P., 2016. The role of hotels in shaping a sustainable built environment. NewDist, July (Special Issue-SBE16 Towards Post-Carbon Cities), pp. 511–519.
	Paper VIII	Corino, O., Buso, T., Kurnitski, J., 2015. A future nearly Zero Energy Hotel in Italy. REHVA Journal, (6), pp. 28–32.
How to include co-benefits in valuation procedures?	Paper IX	Buso, T., Becchio, C., Yilmaz, A.Z., Corgnati, S.P., 2016. Energy Efficiency and Financial Performance of a Reference Hotel - Proposing a Global Cost-Benefit Analysis. In P. K. Heiselberg, ed. CLIMA2016 - proceedings of the 12th REHVA World Congress
	Paper X	Buso, T., Dell'Anna, F., Becchio, C., Bottero, M.C., Corgnati, S.P., 2017. Of comfort and cost: Examining indoor comfort conditions and guests' valuations in Italian hotel rooms. Energy Research and Social Science, 32, pp. 94–111.

Chapter 2

2. Towards a low-carbon building stock in Europe

2.1 Overview

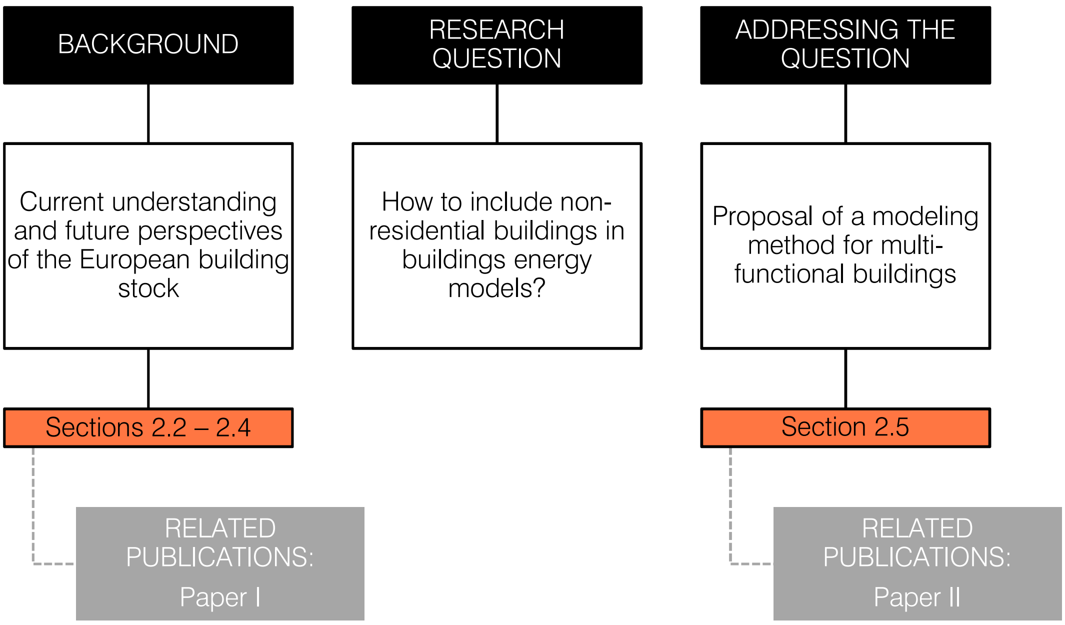


Figure 2-1: Schematic summary of Chapter 2's objectives and contents

The chapter's contents aim at contributing to draft strategies for the high performing energy retrofit of the European building stock. It proposes an overview of the current composition and energy performance of the stock (section 2.2) in relation with the energy and low carbon target set for Europe for the next decades (section 2.3). The main issue arising is the dichotomy between the reality of the building stock and the strategies currently in place for its energy performance upgrade. On one side, studies on the EU the building stock reveal a very low renovation rate and denounce non-residential buildings as an energy intensive and heterogeneous sector. On the other hand, building energy efficiency targets that will be in force in the very next future do not consider existing buildings to be retrofitted and do not provide tailored requirements for non-residential buildings in most of EU Member States. Additionally, recent studies show that carbon reductions trends require a sharp decrease, if the 2050 low carbon target have to be met. In this framework, building stock energy models are powerful tools for the development of effective energy efficiency strategies for the built environment. Section 2.4 provides an overview of the available approaches to building stock energy models, stressing the role that Reference Buildings have in EU energy efficiency strategies. However, due to the poor understanding of the non-residential sector, these models often ignore these energy intensive buildings. As a result, energy reduction targets for non-residential existing buildings are often not included in short term nor in long term strategies, hindering the progress towards a low carbon built environment.

Building upon these premises, the research question that this chapter wants to contribute to is:

How to include non-residential buildings in buildings energy models?

To address it, a tailored modeling method for creating Reference multi-functional Buildings was proposed (section 2.5). Multi-functional buildings represent a broad and transversal category of non-residential buildings, going beyond the traditional building classification (e.g. educational buildings, hospitals, offices, ect.). Indeed, they include all those buildings where multiple functions are in place under the same roof. A systematic approach to the description of these buildings can foster their inclusion in energy models, refining their accuracy. To facilitate the introduction of Reference multi-functional Buildings in the EU library of archetypes and in energy models, the methodology was based on the most popular EU building modeling techniques.

2.2 Current understanding of the EU building stock

Information availability regarding the European building stock is the necessary precondition for any consistent energy efficiency policy. Indeed, the assessment of the existing technical and economic opportunities, feasibilities and limits is required for the development of renovation tracks for the building sector. In view of these facts, several activities were promoted in Europe to go beyond the scattered information given in national monitoring plans and to provide an organic - and open to all - description of the EU building stock as a whole. In 2011, the Buildings Performance Institute Europe (BPIE) published the results of an extensive survey across EU27 Member States, Switzerland and Norway (Atanasiu 2011). This report provided an overall picture of the European building stock in terms of composition and energy performances, listed and analyzed pros and cons of EU directives and building codes and proposed energy performances scenarios based on these outcomes. The project ODYSSEE-MURE (2010-2012) aimed at providing a comprehensive monitoring of energy consumption and efficiency trends as well as an evaluation of energy efficiency policy measures by sector for EU countries and Norway (Eichhammer & Lapillonne 2015). To reach this goal, the project relied on and updated two well-established internet databases, ODYSSEE and MURE. The first reports energy efficiency data and indicators, the latter inform its users about energy efficiency policies and measures. The European project ENTRANZE (2012-2014) further enlarged the picture, providing for EU28 and Serbia additional data about the cost of energy efficiency measures in buildings refurbishment. These data were exploited to develop guidelines to achieve a fast and strong penetration of NZEB and RES-H/C (ENTRANZE consortium 2014). TABULA (2009-2012) and EPISCOPE (2013-2016, follow-up of TABULA) projects gave a sound contribution in the knowledge of the residential building stock (TABULA Project Team 2012; EPISCOPE Project Team 2016). Based on a common methodical framework, sets of exemplary buildings representing different residential building typologies were developed for 20 EU countries. These exemplary buildings were then used to calculate typical energy consumption values and possible energy saving strategies and to elaborate building stock models and scenario calculations. The iNSPiRe project (2012-2016) gathered publicly available information from the residential and offices building stock across Europe to produce representative target examples (iNSPiRe Project Team 2014). These templates were then used to develop and test systemic multifunctional renovation packages with large replication potential.

All these outcomes make available to researchers a huge amount of information to be exploited in any investigation dealing with energy use in buildings. Based on these precious databases and literature, in the followings a picture of the European building stock composition and energy performances is provided, as the fundamental background to understand the relevance of the present thesis in view of improving buildings energy efficiency.

2.2.1 Building stock composition and energy performance

Well-known figures denounce that the building sector is responsible for 40% of the EU energy use and 36% of CO_2 emissions. In 2009 EU27, Switzerland and Norway buildings totaled 450 Mtoe of final energy use. In the big picture, residential and non-residential stock have different ways to contribute to these numbers. The European building stock (EU 28 plus Norway and Serbia) accounts approximately for 27,8 billion m^2 of useful floor area, 74% of which are devoted to residential functions. The remaining 26% comprises a heterogeneous mix of non-residential buildings, characterized by wide variations in construction techniques, energy use patterns and intensity. Figure 2-2 provides a country-by-country overview of the distribution of residential and non-residential building floor area per category and the main characteristics of the two macro-categories are reported in the next paragraphs.

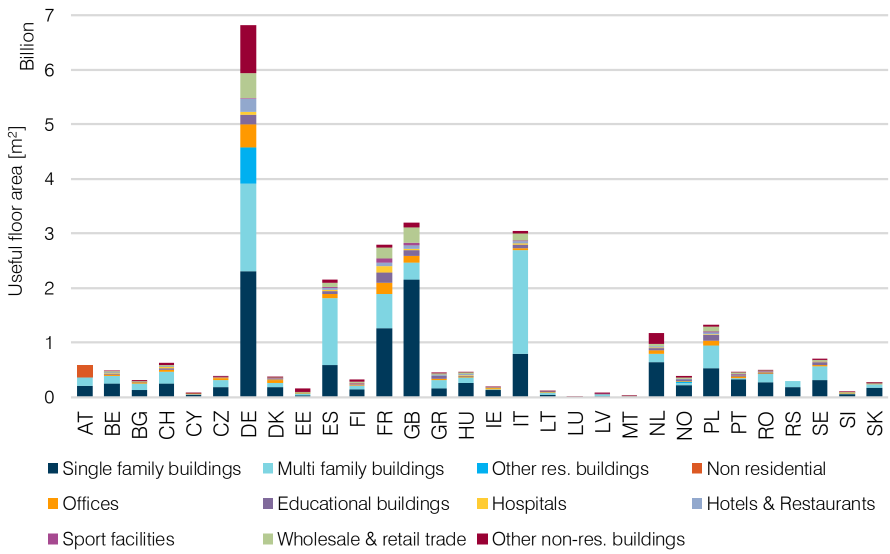


Figure 2-2: Breakdown of residential and non-residential buildings' useful floor area in EU 28 plus Norway and Serbia. Source: BPIE survey (Atanasiu 2011)

Residential buildings

The rather uniform composition of the residential stock allows us to draw an informed picture of its features and performances. The housing stock is generally classified into single-family and multi-family buildings, and the majority of the stock floor area is composed by the former type – 64% (Atanasiu 2011) (see Figure 2-3). The age categorization proposed in the same study reveals that more than 40% was built before 1960 and it makes evident the boom in constructions that Europe experienced in 1961-1990, when the building stock more than doubled in most of Member States. In recent years (1991-2005) new build rate was substantially lower and between 2005 and 2010 the average annual growth rate was around 1%. In terms of ownership, the largest share of residential buildings is private and approximately 20% is owned by public institutions.

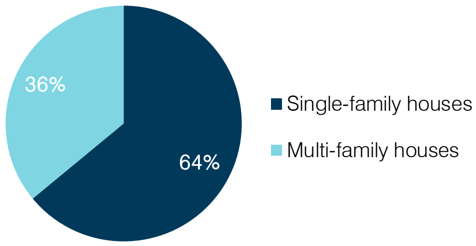


Figure 2-3: Share of residential floor space in EU 28 plus Norway and Serbia. Source: BPIE survey (Atanasiu 2011)

Coming to energy performances, in 2009 the residential stock was estimated to be responsible of 68% of the total final energy use of buildings. Figure 2-4 shows the historical trend 1990-2009 for final energy use, where the increase in electricity uses (+38%) mirrors the increasing penetration of appliances in households. However, the predominant end-use in this sector remains space heating. According to BPIE, it accounts on average for around 70% of the total, keeping in mind the obvious country-to-country and year-to-year variations. Balaras et al. (Balaras et al. 2005), based on the results of 193 energy audits conducted in residential buildings in Denmark, Hellas, France, Poland and Switzerland, identified the average total heating energy consumption – space heating (H) and domestic hot water (DHW) – as around 193 kWh/m^2 and the average energy use for space heating (H) as 129 kWh/m^2. The normalization of the heating performance based on the Heating Degree Days (HDD) of each audited building allowed to depict more general results, respectively 0.073 kWh/(m^2*HDD) for H and DHW and 0.057 kWh/(m^2*HDD).

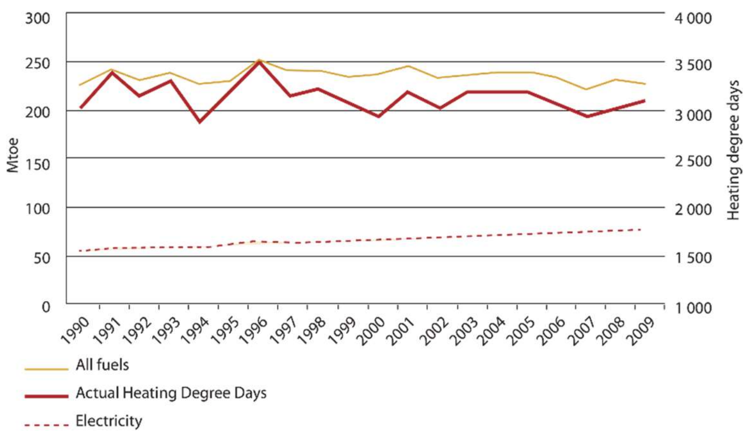


Figure 2-4: Historical final energy uses in the residential sector in EU28, Norway and Switzerland. Source: BPIE survey (Atanasiu 2011)

Non-residential buildings

26% of the European building stock is made up of non-residential buildings, generally classified in offices, educational buildings, hospitals, hotels and restaurants, sports facilities, wholesale and retail buildings and other types of energy-consuming building. The stock composition is highly fragmented (see Figure 2-5) and it widely varies among Member States (see Figure 2-2). Additionally, within each building category, the construction technique, the size, the operational hours and the services provided can differ broadly. For instance, while hospitals, educational buildings and sport facilities are typically large buildings (>1000 m^2), offices, wholesale and retail buildings, hotels and restaurants shows an even distribution among different size bands. Heterogeneity is detected also in the ownership profiles across Europe, where the share of private buildings can spread from 10% (Estonia) to 90% (Greece).

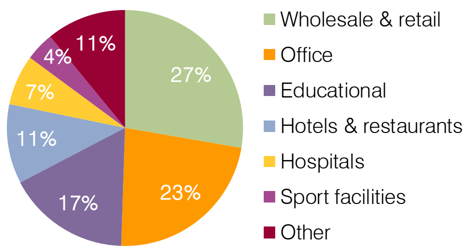


Figure 2-5: Share of non-residential floor space in EU 28 plus Norway and Serbia. Source: BPIE survey (Atanasiu 2011)

Due to the vast diversity among building categories and sub-categories, understanding the energy use of the non-residential sector is a complex task, that is usually tackled at the aggregated level in terms of end-uses. In general, non-residential buildings in 2009 used more than 75 Mtoe of fuels and 70 Mtoe of electricity. Particularly, as shown in Figure 2-6, the use of electricity increased by 74% between 1990 and 2009, as a consequence of the market uptake of appliances and IT equipment. Indeed, the more services a building can offer to its users, the higher their satisfaction/productivity/willingness to pay. Therefore, the growing offer of all sorts of appliances on the market (e.g. air conditioning systems, IT equipment) was warmly welcomed in the non-residential sector. The energy mix breakdown mirrors this vocation to offer services: 48% of energy source is electricity.

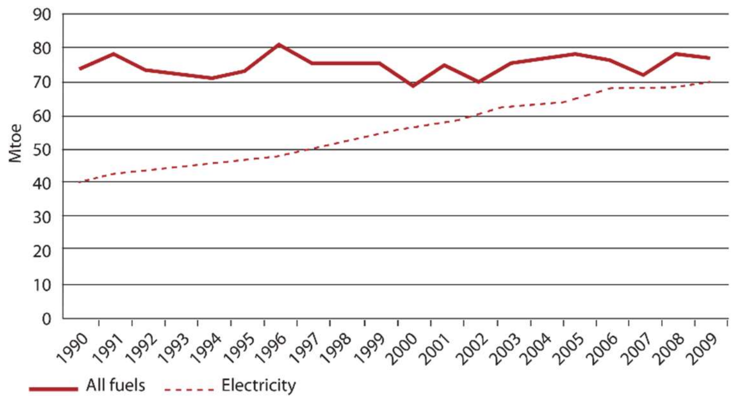


Figure 2-6: Historical final energy uses in the non-residential sector in EU28, Norway and Switzerland. Source: BPIE survey (Atanasiu 2011)

According to BPIE estimations, the average specific energy use of the non-residential sector as a whole, including all end-uses, is around 280 kWh/m^2, which is 40% higher than its residential counterpart. However, while in residential buildings generic normalized values can actually give the idea of the energy performance of the whole sector, the wide variation among non-residential categories does not make this information relevant. The share of total energy use is unevenly distributed among categories and Countries. Furthermore, within each category, sub-categories of buildings can be identified, differing one from the other in terms of energy performances. Based on large databases of energy consumption data, clustering techniques can be applied to single out these sub-categories. For instance, Santamouris et al. (Santamouris et al. 2007) focused on the energy classification of school buildings in Greece, by employing a fuzzy clustering technique; Farrou et al. (Farrou et al. 2012) presented a method to classify hotel buildings based on their electricity and oil consumption, aimed at the creation of benchmarks and reference values; Gao and Malkawi (Gao & Malkawi 2014) proposed a new method for benchmarking commercial buildings, based on the clustering concept of buildings with similar features rather than on the most popular category criteria.

2.3 Perspectives for the EU building stock

The international agreements that in the last decades recognized the climate change issue and promoted reduction of greenhouse gases (GHG) emission strategies, have been the main drivers for European energy strategies. The commitment assumed by Europe with the Kyoto Protocol (UN 1998) was the starting point for the 20-20-20 energy package , endorsed by EU leaders in 2007, as well for the targets up to 2050, that envisage to reduce greenhouse gas emissions by 80-95% compared to 1990 levels. The agreement signed in Paris in 2015 during COP 21 (UN FCCC 2015) , with its legally binding nature, further strengthens the strategic importance of these plans.

As well known, the 2020 energy package goals aim at reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020; increasing the share of renewables in final energy consumption to 20%; reaching a 20% increase in energy efficiency (European Commission 2010a). An intermediate 2030 energy package aims at reducing GHG emission by 40%, increasing the share of renewables production of more than 27%; moving towards a 27% increase in energy efficiency (European Commission 2014). The 2050 targets, finally, focus on GHG emission reduction only. An 80% to 95% overall reduction should be reached, divided cost-effectively among the different economic sectors. In the European Commission’s view by 2050 European citizens “will live and work in low-energy, low-emission buildings with intelligent heating and cooling systems. [They] will drive electric and hybrid cars and live in cleaner cities with less air pollution and better public transport" (European Commission 2011). The EU goal is to shape a low-carbon society, dismantling the traditional link energy - economic development - GHG emission.

Figure 2-7 and Figure 2-8 depict the current EU progress towards these targets. While Members States are well on track for meeting the short-term objectives (see Figure 2-7), the fulfilment of the long terms ones lags behind (see Figure 2-8) (EEA

2016). As a consequence, ambition levels need to be stepped up and all sectors should play their part.

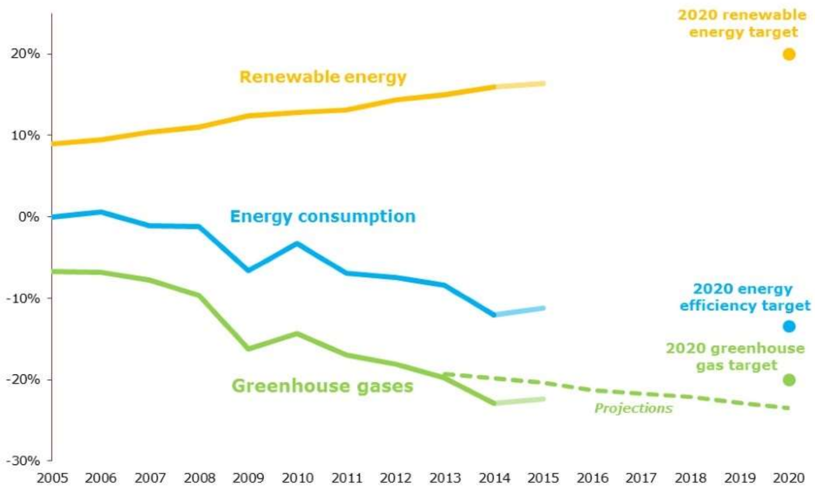


Figure 2-7: EU progress towards 2020 climate and energy targets. Source: EEA report (EEA 2016)

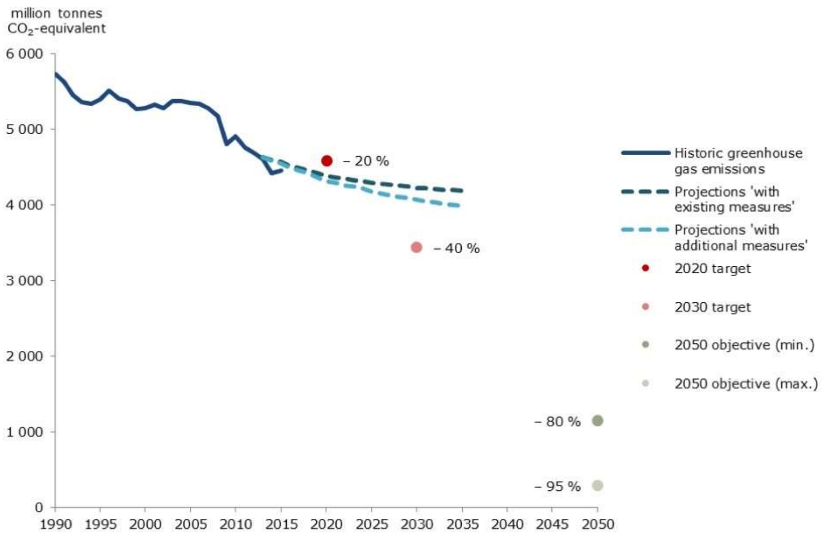


Figure 2-8: GHG emission trends, projections and targets in the EU. Source: EEA report (EEA 2016)

In this context, buildings are key actors. Despite the 2020 energy efficiency targets are expected to be met, the EU building stock transition towards energy efficiency remains slow (e.g. 1% building stock renovation rate), meaning that the contribution of the built environment to the cause was poor in these decades. Buildings' energy saving and carbon emission reduction potential is still mostly untapped and will be crucial to reach the 2050 targets. Indeed, in this sector emissions are expected to reduce of approximately 90% with respect to the 1990 levels. According to Ecofys's projections, the combination of deep building renovation and renewable energies would be the most preferable option to meet this ambitious goal (Boermans et al. 2012). To this purpose, in 2016 proposals for updates were submitted for the major EU directives born in view of reaching the 2020 targets, such as the Renewable Energy Directive, the Energy Efficiency Directive and the Energy Performance of Building Directive. While waiting for their updated versions, at present the Energy Performance of Building Directive recast (EPBD recast) and the Energy Efficiency Directive (EED) constitute the main legislation put in place by the European Commission to reduce energy use in buildings.

Under the EPBD recast (European Parliament 2010):

- energy performance certificates are to be included in all advertisements for the sale or rental of buildings;
- EU countries must establish inspection schemes for heating and air conditioning systems or put in place measures with equivalent effect;
- all new buildings must be nearly zero energy buildings by 31 December 2020 (public buildings by 31 December 2018);
- EU countries must set minimum energy performance requirements for new buildings, for the major renovation of buildings and for the replacement or retrofit of building elements (heating and cooling systems, roofs, walls, etc.) based on the cost-optimal methodology framework;
- EU countries have to draw up lists of national financial measures to improve the energy efficiency of buildings.

Under the EED (European Parliament 2012):

- EU countries make energy efficient renovations to at least 3% of buildings owned and occupied by central government;
- EU governments should only purchase buildings which are highly energy efficient;
- EU countries must draw-up long-term national building renovation strategies which can be included in their National Energy Efficiency Action Plans.

However, as mentioned above, fulfilling minimum requirements will not be enough to score the GHG emission target set for 2050. A widespread advanced upgrade of existing buildings is the envisioned solution. This context justifies the recent success of concepts such as Zero Energy and Zero Carbon buildings.

2.3.1 Short-term perspectives: Nearly Zero Energy Buildings

It is common understanding the Zero Energy Buildings (ZEBs) are energy efficient buildings able to produce energy from renewable energy sources (RES) so that they can compensate their energy demand. Despite the ZEB concept is intuitively clear, the set-up of a consistent definition basis considering all the relevant aspects characterizing the energy uses of these buildings arose as an urgent need in recent years, in parallel with the growing concerns about climate change. Indeed, the robust understanding of the target to be reached is essential for the successful implementation of the ZEB concept in real buildings on a global scale. Several studies faced the challenge (Torcellini et al. 2006; Marszal et al. 2011; Sartori et al. 2012; Panagiotidou & Fuller 2013), giving birth to a structured framework and identifying criteria detailing the general ZEB concept. Based on these studies, Figure 2-9 summarizes the features characterizing the different available approaches to the ZEB concept.

Among the different combinations of features, the most popular in Europe is nowadays represented by near ZEBs, using as metric of balance primary energy related to operational uses accounted on an annual base. These buildings are expected to produce renewable energy on-site and be grid-connected. These near ZEBs should also have low energy needs (i.e. energy efficiency measures are prioritized), which have to be satisfied mostly by RES. The official document where all these features are explicitly recalled is the above mentioned EPBD recast. Indeed, in this directive the concept of Nearly Zero Energy Building (NZEB) is introduced. A Nearly ZEB is generically described as “a building that has a very high energy performance […]. The nearly zero or very low amount of energy required should be covered to a very significant extent from renewable sources, including energy from renewable sources produced on-site or nearby.” The European Commission asks all new buildings to comply with this target from January 2021 on (from 2018 for public buildings).

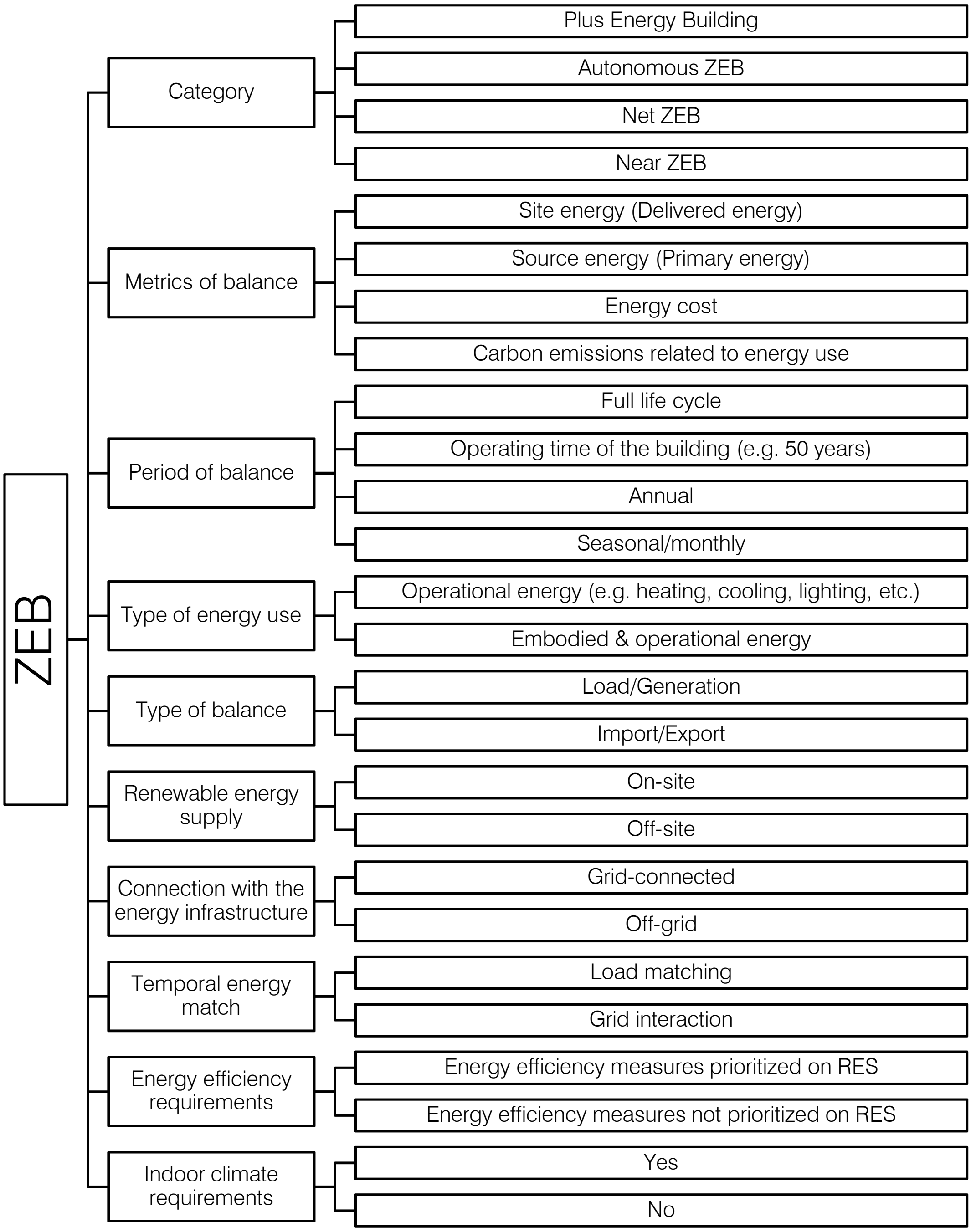


Figure 2-9: Criteria to be considered and features to be selected when defining a Zero Energy Building

With a common base on what kind of ZEB to refer to, task of each EU Member State is to define what exactly “very high energy performance” and “very significant extent” mean, as well as additional specific requirements (e.g. type of balance, temporal energy match, etc.). The EPBD Concerted Action (CA) project has a regular survey on the implementation of the EPBD requirements in MS and BPIE periodically analyses the differences in NZEBs definitions and implementation process among MS. These periodical reviews reveal a dynamic and heterogeneous scenario, object of recurring discussion at the academic level. For instance, Annuziata et al., based on data updated in July 2012, denounced different levels of commitment towards the NZEB target (Annunziata et al. 2013). D’Agostino, instead, based on the available definitions in August 2014, detected a more uniform development of NZEB concept among MS. Nonetheless, differences in type of balance, energy uses included, building categories considered, renewable energy sources included were detected (D’Agostino 2015). In the same line of investigation, the PhD candidate collected and analyzed the national NZEB definitions available by January 2014, highlighting differences in contents and ambition levels, even among countries with similar climatic conditions. Detailed findings can be read in Paper I, enclosed in Part II of this Thesis.

The most updated official document summarizing the progress in the implementation of NZEB definitions at the national level is a report published in 2015 by the EPDB CA (Erhorn & Erhorn-Kluttig 2015), where the national applications of NZEB definitions were evaluated by going through 5 key questions:

- Is there a detailed definition available?
- Is there a requirement for “a very high energy performance”?
- Is there a requirement for “a very low amount of energy required”?
- Is there a requirement for “a very significant extent of renewable energy”?
- Is there a requirement for “a primary energy indicator in kWh/m^{2}y”?

Additional details about the NZEB definitions currently in force are provided in a BPIE factsheet, where figures from Primary Energy indicators are reported, as well as the building typology considered and the possible extension to the NZEB requirements to existing buildings (BPIE 2015). Figure 2-10 merges the main data deriving from these reports.

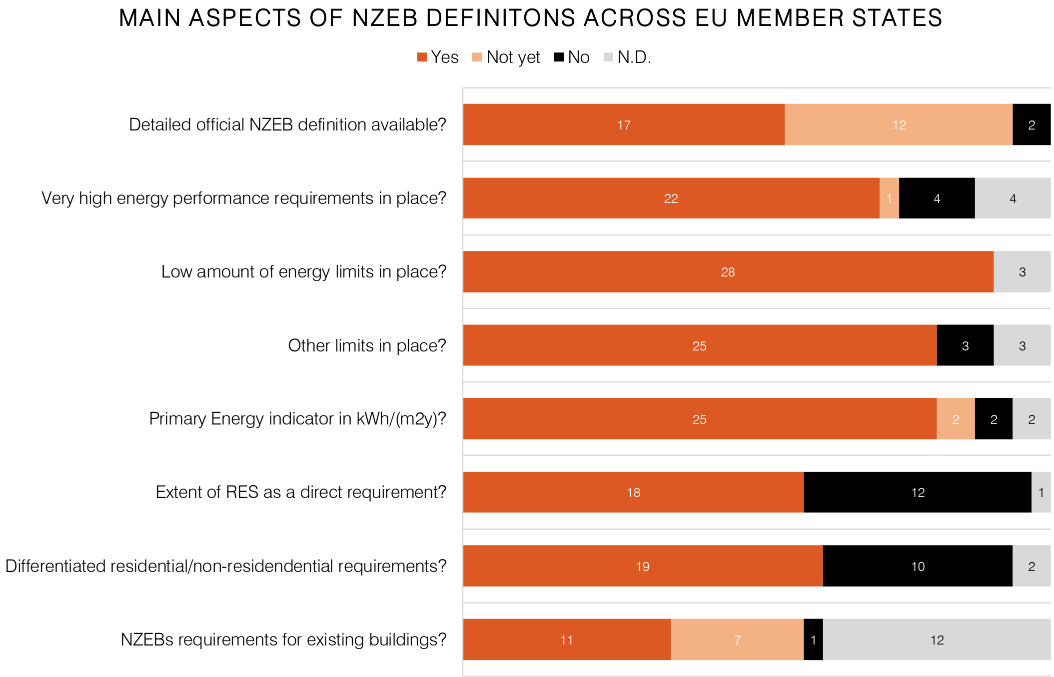


Figure 2-10: Main aspects of national NZEB definitions in EU28 and Norway

Data summarized by these histograms reveal that, in April 2015, approximately 60% of Member Stated had a detailed NZEB definition laid down in an official document. Among the available definitions (official and non-official), around 70% require NZEBs to have very high energy performances, i.e. the building to fall in the top classes of the Energy Performance Certificates or to tighten the minimum energy requirements by a nationally defined ratio. The vast majority of NZEB definitions provide limit values for the use of energy, most often expressed in terms of primary energy uses in kWh/m^{2}y. This requirement is typically coupled with additional requisites related to envelope and technical systems performances and, less frequently, to CO_2 emissions. Explicit requirements for the use of Renewable Energy Sources are given in approximately half of the definitions. In the other cases, RES requirements are indirectly set, meaning that the primary energy use limits are so low that using RES is the only possible solution to reach them. Finally, it is interesting to notice that one third of the available definitions does not distinguish between residential and non-residential buildings in NZEB requirements and that only 11 Member States laid down NZEB requirements for existing buildings undergoing major renovations. Based on the big picture of the EU building stock provided in section 2.2.1, these latter remarks emerge as key issues for the carbon reduction targets. Indeed, the very low renovation rate of the

EU building stock and the very different energy use patterns of non-residential buildings among each other and with respect to residential ones are problems not fully addressed in the current energy legislation.

2.3.2 Long-term perspectives: Zero Energy and Zero Carbon Buildings

With NZEBs becoming a reality in the very next future, the more ambitious Net-Zero Energy target is currently a hot topic in the scientific community, striving to reach a null balance between energy supplied to and drawn from the grid (Evola et al. 2014; AlAjmi et al. 2016; Oliveira Panão 2016; Ascione, Bianco, De Stasio, et al. 2016). Recalling the IEA definition of Zero Net Energy Buildings (Laustsen 2008), these buildings do not incur any fossil fuel debt for operational energy uses, although they sometimes take energy from the grid. As the fulfilment of the EU low-carbon goals requires a sharp fall in CO_2 emissions, significantly reduce the use of fossil fuels in the built environment is a key strategy.

However, as Kilkis argued based on the outcomes of his study (Kilkis 2007), a net-zero energy building may or may not be a net-zero Carbon building, being the impact of a building on the environment not only related to the amount of fossil fuels not used, but also to their CO_2 emissions. In 2008 the International Energy Agency defined Zero Carbon Buildings as buildings that do not use energy that results in net carbon dioxide emissions on an annual base, meaning that they produce enough CO_2-free energy to offset any carbon producing energy (Laustsen 2008).

Within this framework, the national and international organizations are paving the way towards a carbon-oriented analysis of the energy performance of buildings and, consequently, towards carbon-related certification pathways. Among these initiatives, the Zero Net Carbon (ZNC) concept, promoted by the World Green Building Council and Architecture 2030, is one of the newest and most influencing. In the intentions of the promoters, a ZNC building must apply to all building types – new and existing residential, commercial, institutional, and industrial buildings – in various settings, including those located in dense urban environments where on-site renewable energy may be hard to produce, involving the whole built environment in the challenge of reducing CO_2 emissions. Indeed, a ZNC building was defined as "a highly energy efficient building that produces on-site, or procures, enough carbon-free renewable energy to meet building operations energy consumption annually". This concept, by highlighting the possibility of procuring renewable energy from nearby and off-site sources, also strengthen the necessity to consider buildings in terms of their relation among each other.

2.4 Building stock energy models

In view of developing effective strategies towards the low-carbon goals, building stock energy models represent key tools to assist policymakers in long-term scenarios analysis. These models are able to assess the baseline energy consumption, to test different development scenarios and to explore the relations that buildings have among each other and with all the other major sectors of the European energy system, such as transports or industry.

Several modelling techniques are available to produce robust descriptions of the existing building stock, from the aggregated to the single building level. Hall and Buckley, based on a sound literature review, proposed a comprehensive classification scheme for energy system models, accounting for their purpose, structure, mathematical approach and technological detail (Hall & Buckley 2016). In this scheme, energy models of the building stock are classified as sectoral energy models typically built for long-term scenario analysis, in which simulation or optimization methodologies are used to define the energy demand of the sector. Main criteria for their categorization is the analytical approach, "top-down" or "bottom-up". A complete review of these approaches to buildings energy modelling was provided by Swan and Ugursal (Swan & Ugursal 2009). Based on these referenced researches, Figure 2-11 summarizes the most popular building energy modeling approaches.

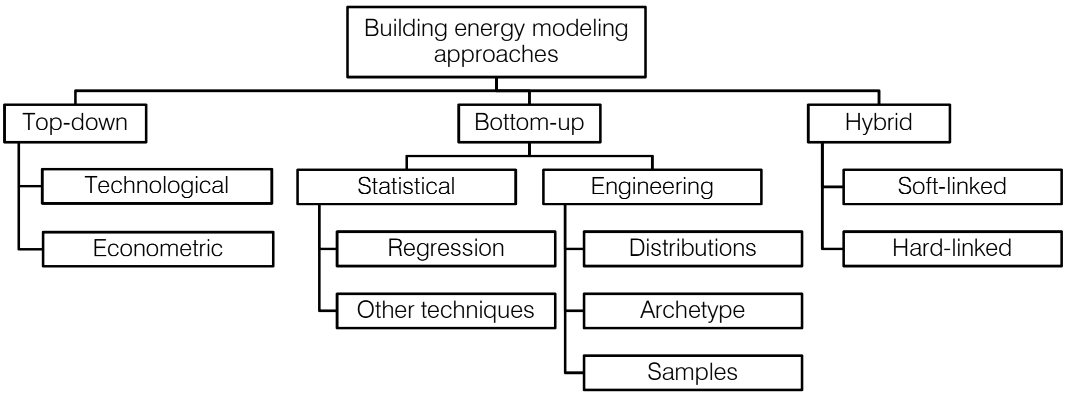


Figure 2-11: Building energy modelling approaches

Generally speaking, “top-down” models are applied to a whole building sector (e.g. the residential sector) to evaluate the macro-economic relations between energy consumption and changes within the sector object of analysis. They require only aggregate data, which simplify the analysis but eliminate the possibility of spotting key areas of improvement. Moreover, they typically aim at fitting energy values in historical series of data and therefore they are not able to model discontinuous advances in technology.

On the other hand, “bottom-up” models aim to identify the contribution of single end-uses towards the aggregate energy consumption of the system under consideration, whose size can range from the building to the nation. They are therefore able to depict energy systems at very different scales. Based on a statistical or engineering approach, these models require as prerequisite for robust results the realistic characterization of the existing stock. Statistical models utilize energy consumption values from a large population of representative sample buildings and apply statistical regression techniques to predict future energy demand based on the initial information. Engineering models calculate the energy use of exemplary buildings based on their geometrical, thermo-physical and operational features. They require many and highly detailed input data, entailing on the one hand the creation of very flexible models able to compare several design alternatives, on the other complications in finding such information. As a further methodological distinction within engineering models, they can use either archetype or samples. Archetypes are limited set of dwellings, representative of a larger stock. Samples are real buildings, selected to represent the variety of the building stock. As the samples approach requires a data availability for a large portion of real buildings, archetypes are the most preferred objects used for the creation of energy models. The simplified energy models developed in the framework of EPISCOPE project well exemplify the archetype-based approach (EPISCOPE Project Team 2016). “Average buildings” were created as theoretical buildings with characteristics mirroring the average of the building stock subset which they represent and projections to the building stock were done by multiplying the “average building” related figures by the total number of buildings of the subset.

In recent years several bottom-up models were developed in Europe, for most of which Kagvic et al. (Kavgic et al. 2010), Soto and Jentsh (Martinez Soto & Jentsch 2016) and Hall and Buckley (Hall & Buckley 2016), in their literature reviews, provide explanatory descriptions comparisons. Despite the detected differences in modelling categories, the long list of analyzed models broadly share a common feature: almost all of them depict and predict the energy use of the residential sector only. On the opposite, energy models related to the whole building stock (residential and non-residential) are rare and uses aggregated data. For instance, the REM (Regional Engineering Model) models municipally aggregated groups of buildings with similar energy use features (Snäkin 2000) and the MAED-2 (Model for the Analysis of Energy Demand) calculates energy consumption for entire building sectors (e.g. housing, commercial) (IAEA 2006).

2.4.1 Reference Buildings

Archetypes are the most popular tools used to model the EU residential building stock. For instance, TABULA and EPISCOPE projects outcomes represent nowadays a well-established reference point for studies aiming at modelling the residential stock. TABULA created a harmonized structure for European building typologies and applied it to the thirteen project partner countries: sets of model of residential reference buildings (from single houses to apartment blocks) were created for Germany, Greece, Slovenia, Italy, France, Ireland, Belgium, Poland, Austria, Bulgaria, Sweden, Czech Republic and Denmark (TABULA Project Team 2012). With EPISCOPE project, the obtained typologies were then further detailed and developed (EPISCOPE Project Team 2016).

The use of archetypes is also officially promoted by the European Commission through the EPBD recast and its accompanying guidelines. These documents introduced the requirement for Member States to define Reference Buildings, as models based on a solid understanding of the current building stock and representative of the typical and average building typologies across Europe. Evidently, the EU definition of RB perfectly matches with that of archetypes provided by the building models-related literature. The so-defined Reference Buildings are the starting point for the national applications of the EPBD recast, in order to set minimum energy performance requirements for new buildings and major renovations. Indeed, minimum requirements should be set in view of achieving cost-optimal levels of energy performance. In order to investigate what does cost-optimal means in various building types among Member States, Reference Buildings are the objects on which hypothetic interventions are applied and evaluated through energy simulations. In the same documents, a sort of formal permission to give the priority to the residential building stock can be spotted. Indeed, Regulation 244/2012 (European Commission 2012a) prescribes as compulsory the definition of one Reference Buildings for new buildings and at least two for existing buildings subject to major renovation for single- and multi-family residential buildings and for offices. For other non-residential buildings, if national specific minimum energy performance requirements do not exist (which is most often the case), MSs can derive them from a basic office RB.

The EU focus on residential buildings models is justified by the deeper understanding of the housing stock, the high share of energy consumption the housing sector is responsible for and its high potential of energy savings. However, due to the high average energy use intensity and the very different use patterns of the non-residential building categories, studies aimed at modeling non-residential buildings are necessary in order to obtain reliable and comprehensive building stock models and to develop effective strategies to reduce buildings energy consumption.

2.5 A modeling method for multi-functional Reference Buildings

The heterogeneous composition of the non-residential building stock is a major issue for the creation of representative archetypes. Non-residential buildings are typically classified according to the main activity they host, e.g. offices, educational buildings, hospitals, hotels and restaurants, sports facilities and wholesale and retail trade services buildings. However, most of these non-residential buildings are in fact multi-functional buildings, where the main function is coupled with side activities (e.g. restaurant, conference hall, swimming pool). These activities, despite being complementary to the core function, represent an important share of the energy uses of non-residential buildings and are often their characterizing elements, shaping, in real life, their business success. Multi-functional buildings (mfBs) are therefore a broad and transversal building category. Nonetheless, they are currently poorly investigated in terms of energy models. Due to the high fragmentation of the multi-functional building stock, studies specifically dealing with multi-purpose buildings are rare and they typically aim at assessing the energy performances of a well-defined case study (Desideri et al. 2013; Gul & Patidar 2015; Christantoni et al. 2015). In order to find a rationale for the realistic modelling of these multi-functional buildings, it is necessary to recall the 3 alternative ways used to define a building (Hobday 2005): (1) building as a complex *assembly of products*; (2) building as a *process* intended to provide services to users; (3) building as a *place to live*, guaranteeing comfort to its occupants. In the evaluation of the energy uses of multi-functional buildings, the interpretation of a building as a *place to live* and as a *process* coexist and alternate depending on the specific function considered.

Building upon these premises, in this thesis a modelling method to define Reference multi-functional Buildings (RmfBs) is proposed, taking EU dispositions about Reference Buildings (EPBD Delegated regulation, guidelines) as a starting point.

The modeling method is made up of 3 subsequent steps:

1. Identification of the relevant energy uses;
2. Definition of the sub-categories of multi-functional buildings;
3. Application of a modelling method to the selected sub-category.

The method is graphically summarized in Figure 2-12.

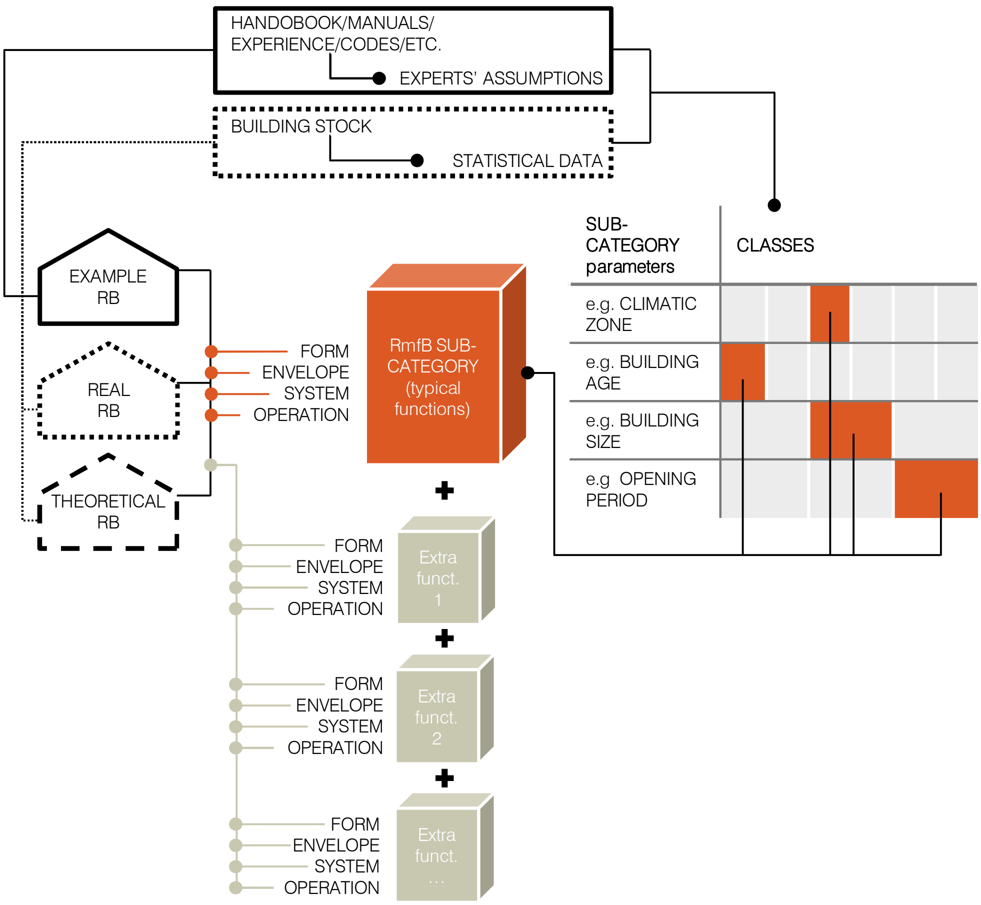


Figure 2-12: Schematic summary of the method for selecting and describing a Reference multi-functional Building

End each step is extensively described in the following paragraphs. Additionally, these contents were object of a journal publication, Paper II enclosed in Part II.

2.5.1 Step 1 - Identification of the relevant energy uses

EPBD recast clearly states that cost-optimal and NZEB levels of energy performance refer to the “typical energy use” of a building and that they are based on calculation performed on Reference Buildings. Therefore, EPBD recast implicitly requires to take into account the typical energy uses of RBs only. For the selection of the proper end-uses to be included in the “typical” ones, the underlying principles of the first EBPD should be recalled (European Parliament 2002). This document suggested that the energy performance of a building depends on the climatic indoor environmental quality targets set for it. Consequently, the typical energy use of a reference building should refer to the end-uses related to the maintenance of the typical indoor environmental conditions. These end-uses are heating, cooling, ventilation, hot water, lighting and – not compulsorily – equipment, used to maintain standard indoor comfort conditions. This approach allows considering the whole building stock as a set of “empty boxes” to which a rather uniform set of energy efficiency measures can be widely applied.

In buildings where maintaining the indoor environmental quality is the main goal, such as residential buildings, the so-defined “typical energy use” is the most suitable parameter for energy evaluations, as it represents the most significant share of the building energy consumptions. Conversely, in multi-functional buildings the typical energy uses need to be flanked by the energy uses related to the extra services offered, in order to realistically depict the energy profiles of these buildings. However, services offered vary widely from building to building, so that a generic percentage increase of the typical energy use is not enough to take extra energy uses into account in energy evaluations.

To overcome these limitations in the definition of non-residential multi-functional reference buildings, multi-functional buildings are here interpreted as a meld of typical and extra functions. Typical functions include the zones where the main aim is to guarantee indoor comfortable conditions; extra functions cover the services offered to users, where the energy uses are chiefly related to the type and quality of the service provided. The typical energy use will be exploited to set benchmarks and minimum energy requirements common to the building category (or sub-category) object of analysis, while extra energy uses will inform about the energy use of the specific building under consideration. The overall building energy performance will then be obtained by superposition of effects.

2.5.2 Step 2 - Definition of sub-categories

As prescribed by EU guidelines (European Commission 2012b), in case of diverse building stock, sub-categorization is a necessary step for the definition of Reference Buildings. It can result either in several RBs within the same category of building or it can be the intermediate step towards determining the most representative RB of the category. In the case of the heterogeneous stock of multi-functional buildings, the first option in recommended.

Because of the variable nature of extra services, sub-categorization of the multi-functional stock makes sense only for the typical energy uses, in order to detect common energy patterns. Additionally, sub-categorization should be based on the most energy impacting parameters of the typical function. Finally, it is recommended that sub-category parameters are classified at the national level, based on local dispositions, experts' assumptions and statistical relevance of the analyzed features across the building stock object of analysis.

2.5.3 Step 3 - Application of a modelling method

For each potential sub-category of mfB, the next step is the identification of the typical function's detailed parameters, required to perform reliable energy calculations. At this stage, a RB modeling method is implemented and the RmfB is created.

Although there is no standard regarding the process to determine reference buildings, procedures exploited are quite similar among different studies. Typically, sets and sub-sets of data required to model the Reference Building are identified and details about these aspects are collected through on-site surveys or existing databases. At the European level, theoretical proposals for harmonized RBs modelling methods were proposed by Corgnati et al. and Brandão de Vasconcelos et al.. Corgnati et al. (Corgnati et al. 2013), inspired by DOE RB models (Deru et al. 2011), defined four sub-sets of information to be collected for the definition of RB – form; envelope; system; operation – and the method was applied for the definition of an existing Italian office RB. Brandão de Vasconcelos et al. (Brandão de Vasconcelos et al. 2016) proposed and alternative method to collect data, grouping them in configuration, constructive solutions and others. By applying their own RB definition method, they drafted a Portuguese multi-family residential Reference Building.

The method proposed by Corgnati et al. is recommended for modelling typical and extra functions of multi-functional buildings, because of a common application background (i.e. commercial buildings). Based on this approach, the main information for typical and extra functions should be gathered for four sections of parameters: Form, Envelope, System and Operation.

- Form section includes: floor area, number of floors, floor height, orientation, shading, aspect ratio, façade area, window/wall ratio, and similar geometrical information;
- Envelope-related set of data presents information about building construction technologies and materials along with their thermo-physical properties;
- System section collects information about the heating and cooling systems, the ventilation system in place, systems for energy generation and production from renewables are given. Data such as HVAC systems type, components efficiency, control settings or lighting fixtures are included in this section;
- Operation set lists the operational parameters affecting the energy use of the building, usually expressed through a set of schedules representing, for instance, building occupancy, lighting, equipment, heating and cooling set-points or ventilation rates.

These data may come from experts' assumptions or statistical data. Based on the available data sources, for each set/sub-set of parameters three different modelling approaches can be applied:

- the "Example Building" approach, based on experts' assumptions and literature;
- the "Real Building" approach, using actual data from existing buildings that have statistically relevant features;
- the "Theoretical Building" approach, including a mix of statistically relevant features to make up a virtual building.

When dealing with multi-functional buildings, the selected modeling method should be applied separately to the typical thermal zones and to each thermal zone dedicated to a specific extra service. In this way, it is possible to attest typical energy uses and to understand the relevance of extra energy uses with the respect to the typical ones. Additionally, this approach makes it possible to evaluate different combinations of functions. A wide range of multi-functional buildings can be represented by combining the same "typical functions" model with different "extra-functions" ones.

2.5.4 Applications in bottom-up engineering building stock models

Transposing the proposed modelling principle at a larger scale (e.g. urban, district, etc.) would entail the classification of the energy performances of non-residential buildings based on parameters that overcome the traditional classification in building categories. Indeed, sub-categories of multi-functional buildings formally categorized in different typologies (e.g. educational buildings, offices, hospitals) may present similar energy patterns in terms of typical energy use. Transversal sub-categories of mfBs could therefore be created, with a categorization based on the most energy intensive features, such as comfort level, construction period or location. Figure 2-13 depicts the envisaged application of the method at large scale, complementing the scheme provided in Figure 2-12.

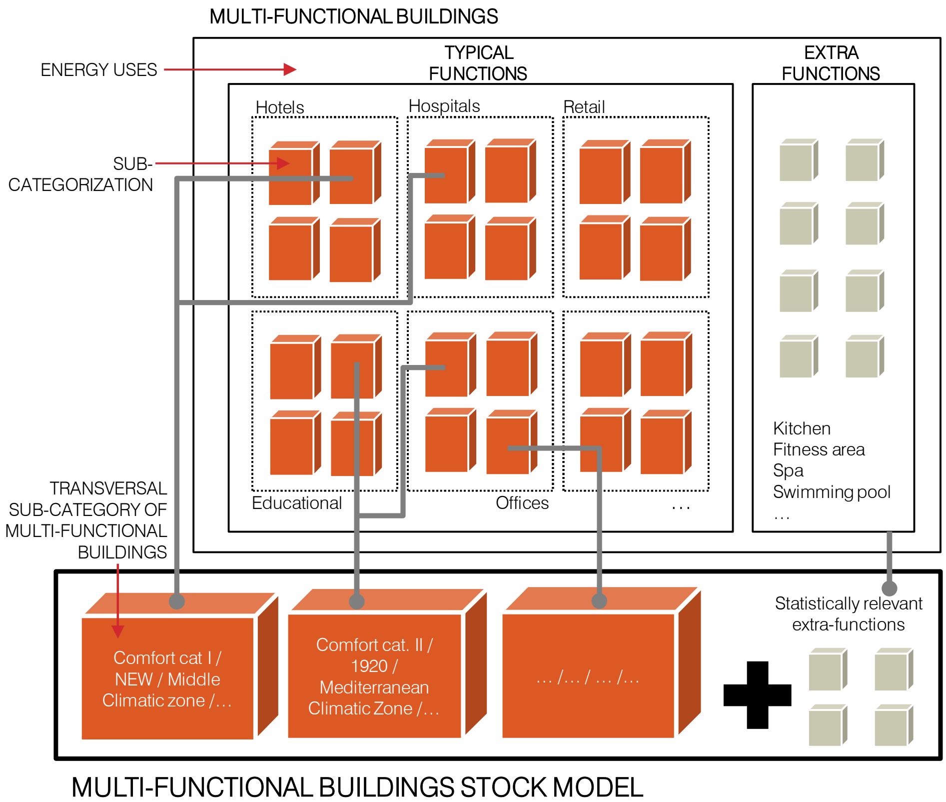


Figure 2-13: Possible large-scale application of the RmfBs modeling method

In general terms, a single benchmark value for typical energy use could be used to coherently represent and evaluate the energy performance of a wide range of non-residential buildings with homogenous characteristics. At this scale, extra-functions can be considered as free-standing elements, added to the model on a statistical basis, to represent the building stock object of analysis.

2.6 Key findings

The original outcome of this part of the PhD research was the proposal of a modelling method for archetypes of multi-functional buildings. Aim of this proposal was to contribute to address the issue of including non-residential buildings in European building stock energy models, as a way to improve their accuracy and effectiveness in defining energy efficiency strategies towards the fulfilment of the low carbon goals.

Through the modeling approach proposed by the author, the modeling problem is simplified: a rationale for the classification of these end-uses is given so that complex multi-functional buildings can be "split" in a set of single functions, which can be classified into typical and extra. Each of these elements can then be then modeled as a self-standing item. Further strength of this approach is that it exploits existing well-established modeling principles and methodologies, facilitating its replicability. Indeed, it distinguishes between typical and extra energy functions based on the EU definition of typical energy use of building, it exploits well-established Reference Building modeling methods for the definition of both typical and extra energy functions, and it suggests how to use this approach in the archetype building stock modeling method, very popular among EU Member States.

Chapter 3

3. Environmental performances of the hotel sector

3.1 Overview

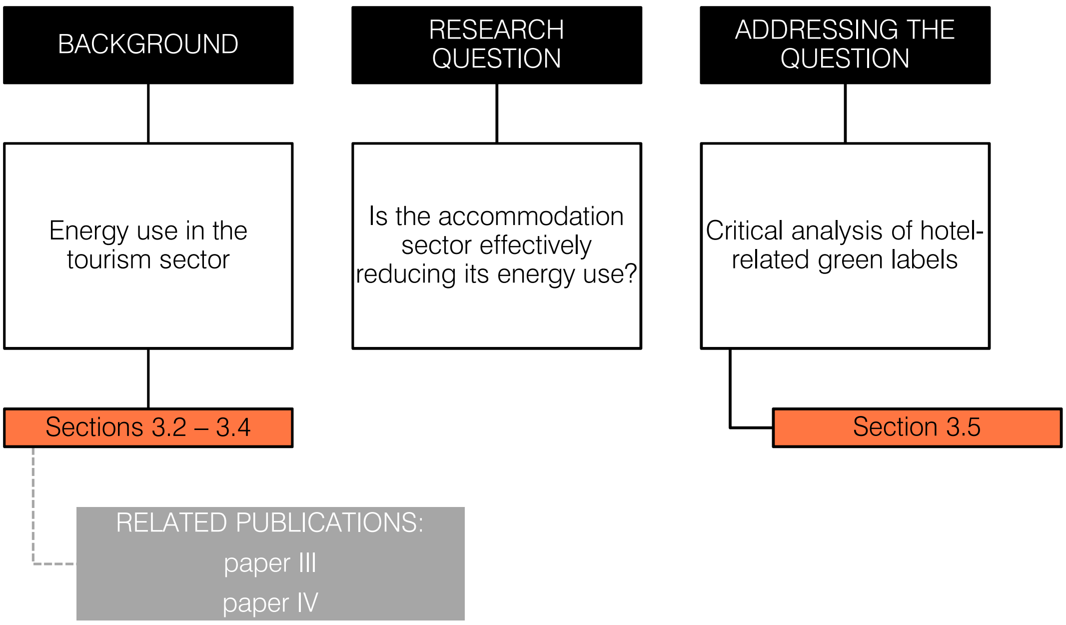


Figure 3-1: Schematic summary of Chapter 3's objectives and contents

This chapter frames tourism activities into the global low-carbon challenge, with specific focus on accommodation sector. Section 3.2 recalls key figures and facts that justify the interest of international institutions towards sustainable tourism. In section 3.3 the attention is shifted to the energy use in European hotels. Relevant initiatives to reduce the energy use of this building category are reported, together with the available data on its energy use. The focus is then further narrowed to the Italian hotel sector (section 3.4). Contents of this section constitute the background knowledge justifying the focus of Chapter 4 on Italian hotels. Based on the analysis of statistical data, researches' outcomes and interviews to relevant stakeholders, the conditions of the Italian hotel stock are depicted.

Data reported at any scale – global, European, national – confirm the need to reduce the environmental impacts of the hotel sector and testify the efforts of this industry towards the goal. However, due to the high fragmentation and poor knowledge of the stock, the effective results of these efforts are hard to quantify. The licit research question that arises is:

Is the accommodation sector effectively reducing its energy use?

In view of answering to this question, the research contribution put forward by this PhD thesis is related to the role of hotel-related green labels in reducing the energy use of these buildings.

Green labels became reference tools towards the 'greening' of lodging industry in the last decades and a plethora of certification schemes is nowadays available to hoteliers willing to certify their environmental impacts. However, a common framework to compare different schemes is missing, causing lack of credibility and market confusion in the field. Additionally, the link between green certification and low environmental impact is not obvious. Houlihan Wiberg, as a result of her PhD thesis, affirmed that environmental certifications are flawed, allowing hotels to be certified even with high CO_2 emissions (Houlihan Wiberg 2009).

Building upon these premises, in section 3.5 a comparison among hotel-related labels is presented. The role that the energy performance of the building and energy efficiency requirements play in the certifications was investigated, as proxy to verify the effectiveness of labels in reducing hotels' CO_2 emissions.

3.2 Environmental issues in the accommodation sector

The ambitious international goals to fight climate change require mitigation actions across all economic sectors. Among them, the tourism sector has drawn special attention towards the achievement of the low-carbon goals in the last decades, to such an extent that the United Nations (UN) General Assembly approved the adoption of 2017 as the International Year of Sustainable Tourism for Development. The UN resolution recognizes “that well-designed and well-managed tourism can make a significant contribution to the three dimensions of sustainable development, has close linkages to other sectors and can create decent jobs and generate trade opportunities” (UN 2015a). Indeed, tourism sector has a potential deep influence on each pillar on which sustainable development is based (economic, social, environmental). The concept of “Sustainable Tourism” coded by the United Nations World Tourism Organization (UNWTO), justifies this statement. Sustainable Tourism is defined as "tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities" and that aims at guaranteeing high tourists satisfaction and at ensuring them a meaningful experience, trying to raise their consciousness about environmental issues (UNEP & WTO 2005). In this sense, UNWTO is deeply involved in the achievement of 3 out of the 17 United Nations’ sustainable development goals (SDGs), which are the pillars of the “2030 Agenda for Sustainable Development”, adopted by 154 government in 2015, during the 70^{th} UN summit (UN 2015b). The 3 goals in which tourism is featured are:

- Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all;
- Ensure sustainable consumption and production patterns;
- Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

In the run towards a low carbon society, consumption and production patterns are the biggest concerns. In 2005 tourism sector as a whole was estimated to contribute some 5% of global CO_2 emissions and the breakdown among sub-sectors highlights that the accommodation sector causes more than 20% of the total emissions, ranking third behind plane and cars transports (UNWTO & UNEP 2008) (see Figure 3-2). These figures gain further relevance when considering the UNWTO projections for tourism sector activities. With a business-as-usual development pattern, the CO_2 emissions in the global tourism sector are estimated to grow of 161% by 2035 (with respect to 2005) (UNWTO & UNEP 2008).

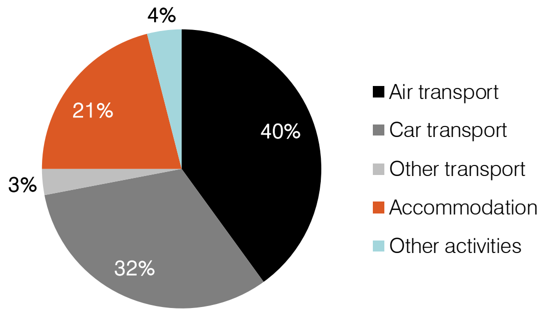


Figure 3-2: Share of CO_2 emissions per tourism sector. Data source: (UNWTO & UNEP 2008)

Luckily, mitigation strategies can reverse the emissions trend. According to UNWTO's projections to 2035, combinations of technological improvements, environmental management, economic and policy measures, and behavioral change have the potential to decrease the CO_2 emissions even below the 2005 level. Figure 3-3 reports the results of 3 emission reduction scenarios with respect to the business-as-usual trends. The maximum technical improvements in all sectors can reduce 2035 projections by 38%; a combination of transport modal shifts, shifts to shorter haul destinations and increasing average length of stay may result in emission reductions by 44%; the combination of both scenarios could entail emissions 68% lower than the business-as-usual estimates (UNWTO & UNEP 2008).

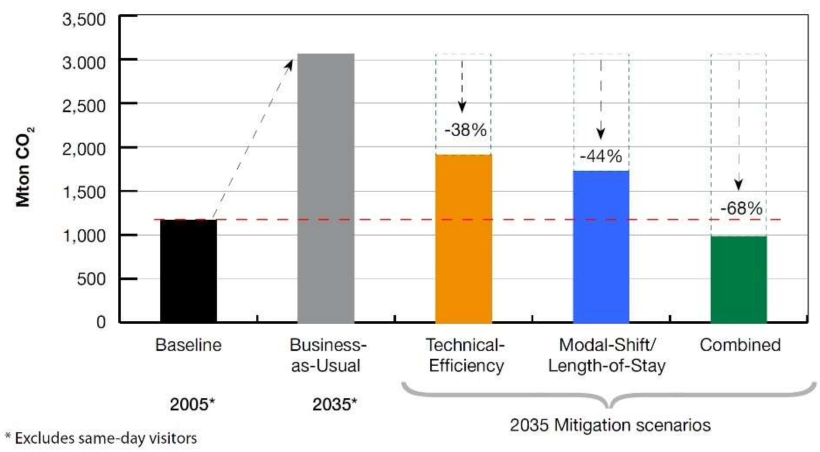


Figure 3-3: Scenarios of CO_2 mitigation potential from global tourism in 2035. Source: (UNWTO & UNEP 2008)

3.3 Energy use in European hotels

UNTWO's estimations attribute approximately 1% of 2005 global CO_2 emissions to the accommodation sector, for which countries are responsible to different extents. Figure 3-4 displays the emissions burden of different graphic areas.

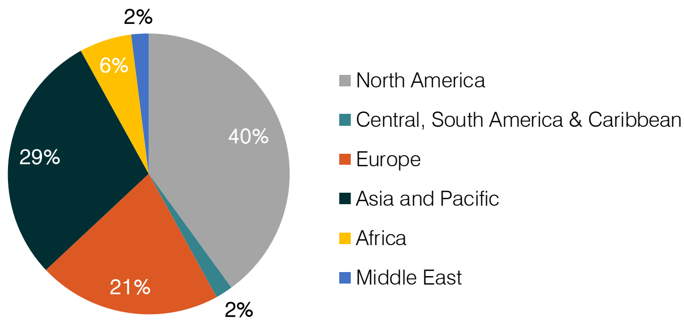


Figure 3-4: Share of accommodation-related CO_2 emissions per geographic area. Source: (UNWTO & UNEP 2008)

Given these challenges, international and local initiatives have put their efforts in reducing the energy use of the hotel sector. At the European level, for instance, a long list of projects addressing these issues have been funded in the last 20 years. The attention put by Europe on hotels is driven by both energy and economic concerns. Dealing with energy, Europe hosts almost half of the world's hotels (Hotel Energy Solutions 2011) and this stock ranks third as energy intensive building category (Atanasiu 2011). From the economic perspective, tourism is the third-large EU industry, under continuous expansions in recent years and responsible of 5% of EU Gross Domestic Product (Hotel Energy Solutions 2011). When including in this framework considerations about the potential for societal change that hotels have (e.g. education of guests), the core role that the energy performance upgrade of these buildings have in Europe's sustainable development – economic, social and environmental - stands out clearly.

The most relevant initiatives promoted by the European Union for reducing energy use in hotels are here briefly recalled in chronological order:

- CHOSE project (1999-2001) investigated the technical and economic viability of combined heat, cooling and power plants (CHCP) in the hotel sector, as well as the energy saving potential through this action. The project has resulted in a method as well as in guidelines on how to measure and evaluate the suitability for CHCP-installations in different types of hotels, resulting from the analysis performed on case studies in 5 countries (CHOSE Project Team 2001b);

- HOTRES project (2001-2003) aimed at the systematic implementation of renewable energies technologies in the tourism industry. Under the umbrella of this project five renewable energy technologies were promoted (solar thermal, solar passive, solar PV, biomass and geothermal energy) in hotels located in five EU regions (East Attica, Sicily, Alpes-Maritimes, Andalusia and Madeira) (Karagiorgas et al. 2006);
- REST project (2002-2004)[1] was designed to lower the carbon dioxide emissions of buildings within the hotel and guesthouse sector, encouraging them to become "carbon neutral" by exploiting on-site and off-site renewable energy sources. Energy audits and action plans aimed at reducing energy bills and CO_2 emissions were delivered to participating hotels;
- HES initiative (2008-2011) sought to bridge the existent gap between available energy efficiency and renewable energy technologies and their actual use in SMEs by proposing an e-toolkit comprised of an energy-benchmarking tool and a decision support sequence. This tool was meant to help in evaluating carbon emissions and mitigation techniques through EE and RE investment options (Hotel Energy Solutions 2011);
- RELACs project (2010-2013) aimed at encouraging accommodations throughout Europe to implement renewable measures as well as energy efficiency practices in their premises. In this view, energy audits and feasibility studies were coupled with capacity building activities for hotel managers and staff (RELACS Project Team 2013);
- neZEH project (2013-2016) promoted the retrofit of SME hotels towards the Nearly Zero Energy Target by supporting and promoting front runners, proposing capacity building activities to hoteliers and professionals and by elaborating national and EU position papers to denounce hoteliers' need (neZEH Project Team 2016).

Additionally, successful private initiatives throughout Europe put in evidence the financial benefits of reducing the energy use in hotels (e.g. entries in the European GreenBuilding project catalogues[2]). Among them, the Boutique Hotel

[1] http://cordis.europa.eu/project/rcn/62772_en.html

[2] http://iet.jrc.ec.europa.eu/energyefficiency/publication/european-greenbuilding-projects-catalogue-2014

Stadthalle stands as a lighthouse example. Since 2010 it is recognized as one of the few nearly zero energy city hotels in Europe. In the context of neZEH project, the PhD candidate was directly involved in the investigation of the strategy and achievements of this high performing hotel business. Outcomes of meetings and questionnaires, published in Paper III enclosed in Part II of this thesis, describe the retrofit intervention as a capital and effort-intensive process, resulted in a successful intervention both in terms of achieved energy performance and of market appreciation.

Despite the concerns about energy use of the hotel sector, knowledge about its energy use remains vague and dated. Reference points for the European context are the results presented by Impiva in 1995, by CHOSE project in 2001, by Bohdanowicz and Martinac in 2007. Impiva's study (IMPIVA 1995) reported typical figures related to the fuel and electricity uses in 3 European hotels types and proposed a ranking (see Table 3-1). CHOSE project (CHOSE Project Team 2001b), based on the results of audits performed in hotels in the partners countries, provided ranges of delivered energy uses (see Table 3-2). Bohdanowicz and Martinac (Paulina Bohdanowicz & Martinac 2007) studied the energy use intensity of 184 Hilton International and Scandic hotels in Europe (2004 data), deriving collective resource consumption, displayed in Table 3-3, and more detailed analyses of a number of physical and operational factors that may influence the energy use in these hotels through a multiple variable regression analysis. Supplementary information about the energy use of the EU hotel stock can be retrieved from EU databases. Table 3-4 reports a summary of the available data about hotels energy performances, as given in Paper IV attached in Part II.

Table 3-1: Typical parameters regarding energy consumption in different types of hotels. Source: (IMPIVA 1995)

Efficiency rating	Good	Fair	Poor	Very Poor
A) large hotels (more than 150 rooms) with air conditioning, laundry & indoor swimming pool				
Electricity (kWh/m^2 year)	<165	165-200	200-250	>250
Fuel (kWh/m^2 year)	<200	200-240	240-300	>300
Total (kWh/m^2 year)	<365	365-440	440-550	>550
Water (kWh/m^2 year)	<220	230-280	280-320	>320
B) Medium-sized hotels (50-150 rooms) without laundry, with heating & air conditioning in some areas				
Electricity (kWh/m^2 year)	<70	70-90	90-120	>120
Fuel (kWh/m^2 year)	<190	190-230	230-260	>260
Total (kWh/m^2 year)	<260	260-320	320-380	>380
Water (kWh/m^2 year)	<160	160-185	185-220	>220
C) Small hotels (4-50 rooms) without laundry, with heating & air conditioning in some areas				
Electricity (kWh/m^2 year)	<60	60-80	80-100	>100
Fuel (kWh/m^2 year)	<180	180-210	210-240	>240
Total (kWh/m^2 year)	<240	240-290	290-340	>340
Water (kWh/m^2 year)	<120	120-140	140-160	>160

Table 3-2: Minimum-Maximum energy consumptions of audited hotels in EU country partners of CHOSE project. Data source: (CHOSE Project Team 2001b)

Country	Minimum-Maximum energy consumptions
Cyprus	103–370
Greece	72–519
Italy	249–436
Portugal	99–444.6
Sweden	198–379

Table 3-3: Statistical overview of the energy consumption indicators in 184 Hilton and Scandic hotels. Data source: (P. Bohdanowicz & Martinac 2007)

	Total Energy per unit area (kWh/m^{2}year)	
	Hilton (N=73)	Scandic (N=111)
Median	336,3	269,9
Mean	364,3	285
1st quartile	280	218
3rd quartile	432	331
Minimum	129,3	123,7
Maximum	859,2	567,2

Table 3-4. Max→min range of energy use for hotel buildings in some European Member States, extracted from the BPIE data hub. Source: (Buso et al. 2014)

Country	Age groups	Hotels and restaurants [kWh/(m²*a)]
Bulgaria	< 1946 – 2004 <	350 → 217
Czech Republic	< 1900 – 2002 <	430 → 290
France	< 1975 – 2005 <	397 → 292
Latvia	< 1940 – 2010 <	185 → 140
Norway	< 1983 – 2011 <	296 → 220
Slovakia	< 1951 – 2006 <	545 → 190

Unfortunately, the reported data do not provide solid benchmarks for understanding the energy use of the hotel sector. All the referenced studies agree in affirming that actual energy uses in hotels are deeply affected by hotel size and age, category, number of rooms, occupancy, opening period, customers' profiles, location, climate zone, as well as services and activities provided to guests. These parameters are classified by Bohdanowicz and Martinac (Paulina Bohdanowicz & Martinac 2007) as:

- Physical parameters: weather, architectural and construction characteristics, age of the facility, energy carriers, water supply system, and air-conditioning system
- Operational parameters: operational practices (laundries, swimming pools and spas, recreational and business centers, etc.), services offered, fluctuations in occupation and variations in customer preferences with respect to indoor comfort.

A further differentiation in energy uses can be made within each hotel building itself. IMPIVA's study (IMPIVA 1995) proposed each hotel building as the architectural combination of 3 different zones, serving different purposes and with different energy flows:

- The guest room area (bedrooms, bathrooms);
- The public area (reception hall, lobby, bars, restaurants, meeting rooms, swimming pool, sauna, etc.);
- The service area (kitchen, offices, store rooms, laundry, staff facilities, machine rooms and other technical sections).

More recently, neZEH project differentiated a hotel's functions into hosting and non-hosting (see Paper IV). The first include the core zones of each hotel business, such as guestrooms, halls, offices, reception, service rooms; the latter include the additional services offered to guests, highly variable from one hotel to the other. An informed picture of the hotel stock energy performance should take into account all these variables.

3.4 The hotel sector in Italy

With 34000 structures, Italian hotels represent the 18% of the EU stock and they directly contribute 4% to the Italian Gross Domestic Product (GDP) (Minuti 2014). Indeed, Italy ranked 5th among the preferred global tourism destination, with number of international arrivals constantly increase in recent years, and it ranked 7th for tourism related incomes (UNWTO 2016).

Generally speaking, 3-stars medium size hotels represent the majority of the structures. However, the composition of the stock is heterogeneous. Figure 3-5, Figure 3-6 and Figure 3-7 show how fragmented the stock is, respectively in terms of number of businesses and beds per hotel class and in terms of size. Additionally, the average dimensions of Italian hotels is related to their class, as shown in Table 3-5.

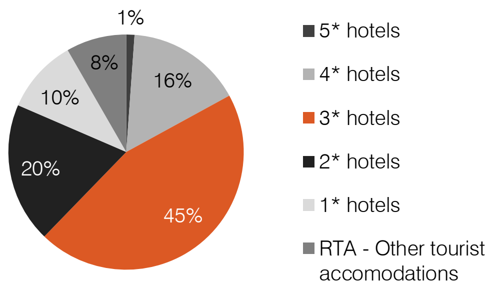


Figure 3-5: Share of hotel businesses per hotel class in Italy. Data source: http://dati.istat.it/

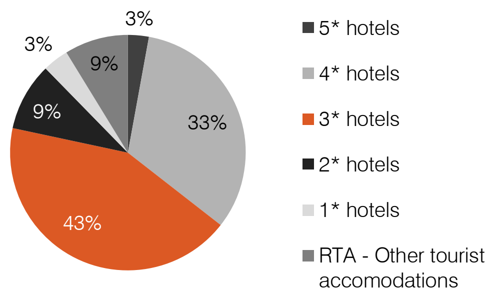


Figure 3-6: Share of beds per hotel class in Italy. Data source: http://dati.istat.it/

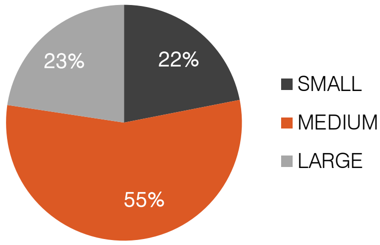


Figure 3-7: Share of beds per hotel size in Italy, where SMALL hotels have up to 24 guestrooms, MEDIUM hotels have up to 99 guestrooms and LARGE hotels have 100 guestrooms or more. Data source: http://dati.istat.it/

Table 3-5: Average Italian hotels dimensions. Data sources: [a] (Minuti 2014); [b] (Aprile 2009)

Hotel class	Average beds number [a]	Average rooms number [b]
1 star	23	10 -15
2 stars	32	
3 stars	64	30
4 stars	138	65
5 stars	163	90

Construction periods of Italian hotel buildings may be inferred from the historical data on number of businesses. As shown in Figure 3-8, from 1930 to 1970 the number of hotels almost increased by a factor of 10, and then faced a slow decline, meaning that most the stock is composed by old buildings.

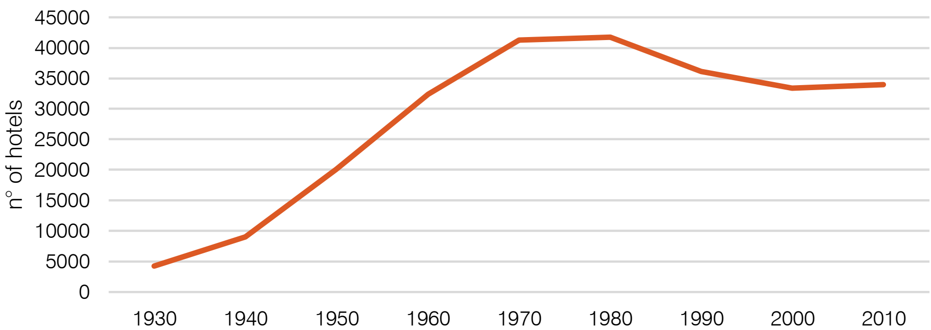


Figure 3-8: Number of hotel businesses registered from 1930 to 2010. Data source: (Becheri et al. 2014)

Finally, Figure 3-9 shows that most of hotel businesses are located in the Northern part of Italy. However, the lower number of business in the South is counter-balanced by their bigger dimensions (in terms of number of beds). Confirming the link between hotel dimensions and class, accommodation structures in South Italy have in general higher class than hotels in the North (Minuti 2014).

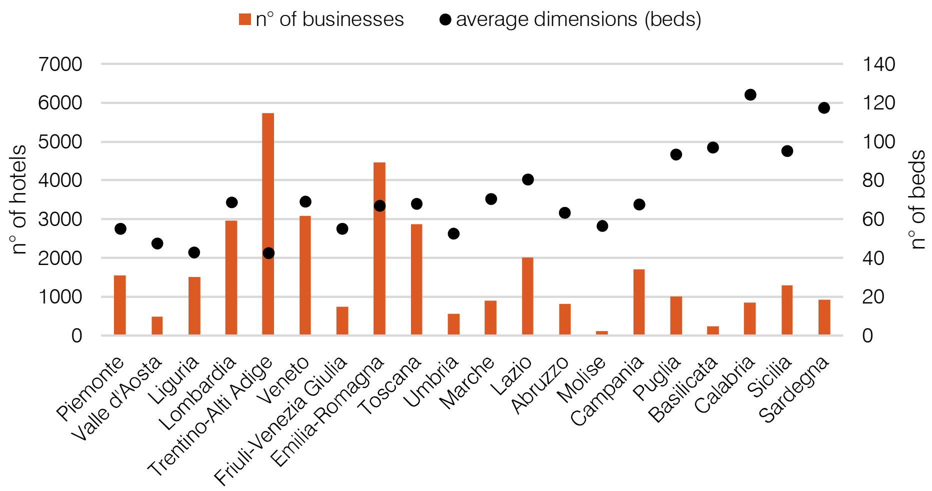


Figure 3-9: Number of hotel businesses per region (orange bars referred to left y-axis) and average dimension (beds) of hotel businesses (black dots referred to right y-axis). Data source: (Becheri et al. 2014)

3.4.1 Energy use in Italian hotels

Despite the strategic importance of this sector, studies related to the energy characterization of the Italian hotel stock are rare. As displayed in the previous paragraphs, the Italian hotel market is highly fragmented concerning size, quality, occupation rate, services rendered, market development etc. Consequently, the energy needs of hotels have a very wide range of variation, that is challenging to depict. Electricity and natural gas are the more widespread energy carriers in the hotel sector, followed by oil and GPL (Aprile 2009), but how these energy sources are used in hotels cannot be summarized in few figures, if a realistic overview is required.

CHOSE project obtained through audits the average data of energy uses for a selected group of Italian 4-stars hotels, open all-year, with conference room, restaurant and laundry and an average dimension of 150 rooms (CHOSE Project Team 2001a). A survey on 4-5-stars hotels throughout Italy, open all year, with an average dimension of 100 rooms, provided information about the average electricity uses(Studio Roberto Fortino e Associati 2005). Beccali et al. (Beccali et al. 2009) focused on the on Sicilian hotels' thermal and electrical energy consumption. Based on the description of the census data, sample Sicilian hotels where selected and audited in order to rank potential energy saving measures. A national report (Aprile 2009) presented results of building energy simulations of 2 reference hotels (3 stars and 48 rooms – 4 stars and 112 rooms), giving figures about reference energy consumption for heating, DHW, cooling and electricity for different hotel types in Northern, Central and Southern Italy.

Table 3-6 summarizes the main numerical findings of the quoted studies, in terms of average energy consumption of the analyzed hotel stock.

Table 3-6. Average energy uses of selected Italian hotel categories, based on literature findings. Data sources: a (Beccali et al. 2009); b (Aprile 2009); c (CHOSE Project Team 2001a); d (Studio Roberto Fortino e Associati 2005)

Hotel cat.	Macro Clim. Zone	Ref.	Source of energy [MWh/(room*a)]		End-uses [MWh/(room*a)]			
			FUEL	ELECTR.	HEAT.	DHW	COOL.	EQUIP. & LIGHT.
1-2*	South	a	2,2	1,6	-			
3*	North	b	6	5	3 (B) 1,8 (L)	4,8 (B) 3,8 (L)	1,3 (B) 2 (L)	3,3 (B) 3,2 (L)
	Centre	b	-		1,3 (B) 1,8 (L)	4,8 (B) 3,8 (L)	2 (B) 2 (L)	3,3 (B) 3,2 (L)
	South	a	5,3	4,7	-			
		b	-		0,4	3,8	2,7	3,2
4* (#4/5*)	North	c	54,1	6,6	4,6	4,4	1,2	
		b	-		3,7 (B) 2,1 (L)	4,8 (B) 3,8 (L)	1,3 (B) 1,9 (L)	5,2 (B) 5,1 (L)
		d #	-	7,7	-			
	Centre	c	25	9,7	4,1	4	2,9	
		b #	-		1,7	4,8	2	5,2
		d #	-	7,7				
	South	a	8,7	4,2	-			
		b	-		0,7	3,8	2,7	5,1
		d #	-	7,7	-			

Note: (B)=Business hotel; (L)=Leisure hotel

3.4.2 Retrofitting Italian hotels: hoteliers' needs and proposals to policy makers

The old age and the high energy use of Italian hotels constitute breeding ground for the implementation of energy efficiency measures in these buildings. However, studies highlight that retrofit projects are generally mistrusted by investors, due to policy, market and technological barriers. High investment costs, poor knowledge of energy efficiency issues and their possible benefits, lack of specialized hotel technical staff are among the most acknowledged issues for the Small-Medium size businesses (Hotel Energy Solutions 2011), which constitute almost 80% of the Italian stock.

In the context of neZEH project, these barriers and possible solutions were investigated for each of the 7 partner countries. The PhD candidate was directly involved in the investigation of Italian hoteliers's needs in view of improving the energy performance of their business towards the Nearly Zero Energy Target. The investigation resulted in a national position paper available at:

http://www.nezeh.eu/assets/media/PDF/D2390.7%20National%20Position%20Paper_IT_EN.pdf

Excerpts of the document, edited by the PhD candidate under the supervision of SiTI project team involved in neZEH project, are here reported and re-arranged to provide the reader with an overview of opinions and needs of Small-Medium hotels' owners in terms of tools needed to support high efficiency energy retrofit measures in their sector.

"*In order to have a realistic and comprehensive overview of hoteliers' needs and opportunities in this field, SiTI drafted the Italian position paper taking advantage of the expertise of policy makers, a local financial institution, associations supporting local businesses, national and local hotel associations, hotel owners and also other relevant actors in the field of energy efficiency. The contacted actors were already part of SiTI network and most of them were involved in neZEH Local Committees.*

On one side, SiTI exploited the information collected in the first 18 months of neZEH, during which meetings with relevant stakeholders were organized. On the other hand, specific questions aimed at the finalization of this position paper were addressed to the involved actors. The chosen approach to interview these actors was to send emails presenting neZEH and the aim of the position paper, enclosing a short list of questions (personalized according to their expertise) to be answered via email or in person. Dealing with hotel owners, they were contacted both via email with a questionnaire, sent to all the members of tourism local associations locally involved in neZEH, and in person, with interviews to the applicants to the neZEH call for pilots.

The contacted ***policy makers*** *are:*

- *Città di Torino – Assessorato Ambiente (TAA)*
- *Fondazione Smart City (FSC)*
- *Regione Piemonte – Energia (RPE)*
- *Regione Piemonte – Turismo (RPT)*

*The contacted **local financial institution** is:*

- *Finpiemonte (FP)*

*The contacted **associations supporting local businesses** are:*

- *Unioncamere Piemonte (UCP)*
- *Camera di Commercio di Torino (CCT)*

*The contacted **hotel associations** are:*

- *Confindustria Alberghi (CIA)*
- *Unione Industriale di Torino (UIT)*
- *Federalberghi Piemonte (FAP)*
- *Federalberghi Italia (FAI)*
- *Federalberghi Torino (FAT)*

*The contacted **other actors** are:*

- *Federesco (federation of Italian ESCo companies) (FE)*
- *Edilportale (the most famous Italian web portal for building professionals) (EP)*

The quality of the answers allowed drafting a comprehensive overview of the current hotel sector needs and characteristics (codes in brackets are used in the following paragraphs to properly attribute each contribution)."

3 aspects were chiefly analysed in the position paper: (a) support policies, (b) technical assistance and (c) capacity building and awareness raising.

a) Support policies - current situation

"Energy efficiency in hospitality sector is taken into account from a general point of view in the energy efficiency policies (i.e. hotels are not object of specific policies) and from a more focused standpoint in policies for tourism.

Energy efficiency policies

The main incentives scheme available nationwide promoting the uptake of energy efficiency in existing private buildings, including hotels – but not focusing just on them – are:

- ***Tax deduction*** *for energy efficiency improvement actions. 65% deduction of gross tax (progressively reduced in 2017) for projects obtaining an* EP_H *at least 20% lower than the reference values;*
- ***The thermal account*** *incentivizing the generation of thermal energy from Renewable Energy Sources and small scale energy efficiency projects;*
- ***White certificates****, that are tradable securities certifying the achievement of energy savings in the final uses of energy through energy efficiency measures and projects.*

Among them, according to National Energy Strategy (SEN) 2013, the most effective measure for residential sector and services is tax deduction.

Other available funding supporting energy efficiency in buildings are:

- ***European Structural Funds 2014-2020;***
- ***National Fund for Energy Efficiency;***
- ***Funds for hotels refurbishment****, to be adopted in October 2014, included in DEF 2014.*

[...] From the experience in interviewing hoteliers, their knowledge about the regional and national funding opportunities emerged to be good and up to date (they ask for information about the European funding schemes). Unfortunately, the availability and the widespread information of local funding possibilities didn't boost the number of applicants taking advantage of these opportunities. Among hoteliers, two main restraints in applying for funding for buildings' energy efficiency were detected: the very technical language (understandable just by energy experts) used in policies texts and the extremely long bureaucratic process required by the applications rules [RPE, UIT].

Moreover, a critical review from the policy makers' standpoints about the available funding possibilities for energy retrofit pointed out that current policies have promoted preferential energy efficiency measures, which turned out to be not so successful in reducing energy consumption (e.g. PV panels, heat pumps). A wider range of option should be financed [RPE].

Tourism policies

*Dealing with specific policies for tourism, decree D.L. 83/2014, named „****artbonus and tourism decree****", envisage a 30% tax credit for hotels' refurbishments.*

However, it is still not clear whether and how tax deductions and funding related to the energy efficiency policies will interact with the tax credit included in the quoted tourism decree.

At the current stage, no coordination among policies in the two fields is detected by the involved stakeholders. Indeed, current energy efficiency national plans are transpositions of European Directives, in which the focus is on intervention typologies rather than on building functions [UIT]. Coordination between buildings' energy efficiency and hotels sector policies is among the priorities to be addressed to policy makers.

Private credit

Beside the access to public support measures, also getting credit from the bank is very hard. When asking for loans for this kind of intervention, banks ask for additional real warranties [FP, UIT]."

b) Technical assistance for hotels' refurbishment projects – current situation

"Technical knowledge and assistance for hotel owners is a key issue toward the implementation of energy retrofit projects and, among the interviewed stakeholders, it is also one of the most mentioned issues preventing the implementation of energy retrofit projects.

No technical assistance at the public level is available nowadays and hoteliers willing to refurbish their hotels needs to directly contact an audit firm/ESCo/design firm to have suggestions on how to optimize their energy performance. Moreover, in small-medium hotels run by privates (mainly families) - representing the majority of the Italian hotel stock – the selection criteria for design companies/building professionals to be charged of a retrofit project/realization is often acquaintance rather than field of expertise, entailing design solutions with traditional features instead of daring new experimentations. Indeed, these professional figures are on average not updated to the most recent energy requirements or technologies and relies on the application of traditional (safe/well known) solutions, blindly trying to fit with energy requirements that they perceive as binding and overestimated [RPE].

In this framework, support measures aiming at provide technical assistance to hoteliers are somehow proposed by D.L. 102/2014, in which regional funding programs for energy audits in SME are introduced. Particularly, being energy audits the first step of a refurbishment project, funding will be given to applicants only once the energy saving measures suggested by the audits are implemented and measured or certified."

c) Capacity building and awareness raising measures for hoteliers – current situation

"Attention for buildings energy efficiency is still very low among hoteliers. As reported by several interviewed stakeholders [CCT, FP, RPE], the main focus of hoteliers' businesses is still related to tourism in the strict sense, meaning that they are more willing to attend courses and invest money on marketing issues rather than sustainability. As a proof, in public seminars about energy efficiency and environmental impact of business activities organized by local business associations, on average only 20% of the invited attendants take part to the lessons. On the opposite, marketing and security requirements seminars are very popular and appreciated among hoteliers.

Raising the attention to energy efficiency among the general public is one of the goals recently set at the Italian legislative level in D.L. 102/2014. Indeed, Article 13 is fully dedicated to information and training of buildings' occupants and professionals: ENEA (National Agency for new technologies, sustainable energy and economic development) together with ESCOs, energy services', costumers' and regional associations, have to develop a 3 years education and training program to promote and facilitate a smart and efficient use of energy."

Special needs of the hotel sector

"Given the general situation of the hotel sector, depicted in the previous paragraphs, 3 main needs are identified for hoteliers willing to refurbish their structures [FSC, TAA, CCT, UIT]:

1) *Easier access to credit for retrofit interventions;*
2) *More understandable laws and/or advices from institutions for laws interpretation in practice;*

3) *First stage qualified technical assistance at the public level, to give hoteliers a general, "independent" and up to date overview of the potential energy savings of their hotels.*

Points 2) and 3) could be also summarized in the need for policies promoting a network among hotels and technicians for energy efficiency issues [RPT].

Beside the practical needs for starting hotels' retrofit interventions, the main gap that need to be filled among hoteliers is the awareness of the raising role played by sustainability in tourism activities: the need for "easy language" information campaigns and training seminars was highlighted as a priority by most of the interviewed stakeholders [CCT, FP, UIT, RPE].

On the other hand, also guests have to be taught to appreciate the added value of staying in a sustainable hotel: in order to make the energy retrofit a profitable investment, there is the need to explain to the general public the advantages and the social value of "going for green" [UIT, RPE]."

Recommendations for policy makers

"Assessing and listing the advantages of investing in green retrofit of hotels is the necessary first step toward any definition of successful policies in this field (very few businessmen would ever apply to a public program only for personal believes). From the interviewed hoteliers and stakeholders, the main pros of becoming a nearly Zero/high performing hotel emerged clearly:

- *reduction of the hotel's operational costs, thanks to the consistent energy demand decrease;*
- *Improved image of the hotel and improved market positioning, meeting the new interest of tourist for sustainability;*
- *Increase comfort as an added value for hotels' guests.*

In order to take advantage of the listed benefits, hoteliers need to be supported by local and national policies to start the refurbishment process, overcoming all the limits previously stated. Recommendations, based upon the needs identified at the EU and Italian level, tackle three main areas: policies for tourism, technical assistance and awareness raising"

a) Support policies

At EU and national policy level two recommendations were explicitly identified. The first one asks policy makers to take into account the specificities of the accommodation industry and of existing buildings, while preparing their national NZEB policies. The latter proposes to stimulate a better dialogue between tourism, energy and building policy makers to facilitate SME hotels engagement towards NZEB regulations at local, regional, national and EU level.

b) Technical assistance

National policymakers are recommended to engage for scaling up the refurbishment of the EU accommodation industry to meet NZEB performance. Suggestions about how address this issue practically were given by the Italian stakeholders interviewed for:

*"**Financial support***

- *Fiscal incentives [TAA, FSC], with incentives proportional to the return of investment and expected increased income of structures undergoing a retrofit intervention [UIT]*
- *Subsidies for design, financial analysis and realization of high energy performance refurbishment projects [RPT]*
- *Tools allowing easier access to credit for investment on energy efficiency measures and use of renewable energy in hotels [FP, FSC]*

Technical assistance

- *Public energy help desk/consultancy services for hoteliers, for first hand and broad direction suggestions about the refurbishment possibilities available [TAA, FSC]*
- *Legal help desk for hoteliers, for explanation in practice of public funding opportunities' eligibility criteria and requirements [TAA, FSC, CCT]"*

c) Awareness raising and capacity building

"Advocacy and tailored awareness raising campaigns targeting the hospitality industry can help to convince hotel owners about the economic viability of becoming a neZEH. It is easier to engage hotel owners that are already committed to sustainability in the discussion about investing in deep energy retrofit. Synergies

with the existing engagement of hotels in different eco-green hotel certification schemes can be exploited when promoting buildings energy efficiency among hoteliers (i.e. by using the EMAS following hotels).

Suggestions of recommendations coming from the Italian stakeholders include:

- *Creation of a nZE/high performing hotels local network, in order to promote a structured offer of new-generation sustainable accommodations [RPE]*
- *Training courses and seminars for hoteliers, providing basic technical knowledge and presenting the advantages – ECONOMICAL and environmental – of investing in high performing refurbishment projects [CCT, UIT, RPE].”*

3.5 Critical review of green labels for the hotel sector

Outcomes of the EU and national position papers presented by neZEH project suggest synergies with green hotel certification schemes as a possible solution to raise hoteliers’ awareness about energy efficient solutions for their businesses. Indeed, sustainability certification schemes are the most common approach SME hotels can relate to, for understanding Nearly Zero Energy level requirements.

Over the past several years, the world’s leading hotel brands have increased their efforts to respond to environmental issues and invested in going green (Kang et al. 2012). Sustainable practices are now pillars of the Corporate Social Responsibility (CSR) programs that the hospitality industry is increasingly implementing and being viewed as a green hotel is often a desired outcome of a hotel’s CSR strategy (Gao & Mattila 2014). Today’s customers are more and more sensitive to ecological matters and greening a hotel is inevitable not just to achieve operational cost savings, but also - and mainly - in order to meet hospitality customers' needs and boost their positive intention and behavior toward the firm (Han & Kim 2010; Han et al. 2011). In this framework, green label has been heralded as a significant step towards the ‘greening’ of lodging industry (Houlihan Wiberg 2009). In 2002 over 100 tourism green labels and certification schemes, with different criteria, contents and scope were available worldwide (Font 2002), out of which over 60 labels account for Europe (Honey 2002). More recent data affirm that nowadays the number of tourism related-green labels exceeds the 140 units (Plüss et al. 2016). Anyway, to effectively figure out the total number of green labels available worldwide is not a trivial task. As market conditions change and the demand for greener products continues to increase, green certifications keep on thriving.

Despite the wide offer of green tourism certifications, a common framework to compare different schemes is missing, causing lack of credibility and market confusion in the field. Sub-section 3.5.1 gives the big-picture about the basic principles upon which any green label relies. Nonetheless, a plethora of hotel certification can be ascribed to each of these macro-categories, each of them with different features and purposes. As a contribution to a more systematic and robust understanding of green labels for hotels, in the context of the PhD research a critical review of a number of green labels applicable to the hotel sector was performed in close collaboration with 2 master students from Politecnico di Torino, Giulia Crespi and Andrea Tartaglino. Through the selection of 19 green labels, presented in sub-section 3.5.2, the most common environmental performance categories mentioned in these certifications were identified (sub-section 3.5.3). Among them, the main focus of the analysis was the role that the energy performance of the building play in the certifications, considered as a proxy for reduced CO_2 emissions. To this purpose, a comparative analysis was performed to investigate the weight of energy efficiency requirements in the selected label schemes and as well as their level of detail and effectiveness. Results are presented in sub-section 3.5.4.

3.5.1 Basic principles of green labels

Green labels (or eco-labels) are voluntary environmental certifications (represented by a symbol), awarded to specific products, including buildings and services, aimed at highlighting their environmental advantages and based on a process of assessing compliance with pre-established criteria (Brilhante & Skinner 2015). Environmental eco-labelling programmes have a history of 30 years, starting with the German Blue Angel in the late 1970's. A proliferation of product-related eco-labels started ten years later and eco-labelling programmes currently exist in large numbers and many forms at national, European and international levels (Bratt et al. 2011). Mirroring the variety of labels available, diverse terminology can be found in literature to name the certification approach related to the environmental performances of products, services and buildings (e.g. "ecolabel" (Bratt et al. 2011; Buckley 2002; Oom do Valle et al. 2012), "eco certification"(Font 2002), "environmental certification" (Buckley 2002)). For the sake of clarity, in the followings any environmental performance certification will be referred to as "green label".

The market success and consumers' understanding of these labels led to transfer the green labelling concept from products and services to the building size. Due to the very different features of the certified items, the shift was not smooth. Indeed, buildings are unique goods, with a longer life than products, subject to change and to multiple uses and users during their lifespan and whose functions are deeply integrated with infrastructures (Zabalza Bribián et al. 2009). Despite these conceptual issues, green labelling has evolved as an important tool for reducing the energy consumption and GHG emissions of buildings, particularly in developed countries (Shi et al. 2016). The green building concept is now used to indicate structures and uses that are environmentally responsible and efficient throughout the building's life cycle (Mahdavinejad et al. 2014). The aim is to build energy efficient, healthy, and productive buildings that can reduce their impacts on urban life and the global environment (Wei et al. 2015).

In order to have a comprehensive picture of green labels schemes, many features need to be detailed. Particularly, green labels can be classified based on the number of attributes evaluated, the evaluation method and the evaluation body:

- **Numbers of attributes**. Green labels can be single-attribute criteria or multi-attribute criteria. Single attribute criteria means that the assessment focuses on one environmental issue (energy efficiency, water or waste management); multi-attribute criteria means that the assessment focuses on two or more environmental impacts (looking at several characteristics of a product or even a product's entire life cycle or a product's impacts) (Brilhante & Skinner 2015).
- **Evaluation method**. Two main approaches are available for evaluating the environmental performances of a product/service/building: process- and performance-based. Process-based schemes impose management activities finalized to reduce environmental impacts (holding staff seminars to encourage staff into energy saving practices). Performance-based schemes are instead built on measurable results (e.g. energy consumption). While process-based schemes define a system for monitoring and improving performance, performance-based methods state the goals or targets that must be achieved to receive certification and use the logo (Houlihan Wiberg 2009). At present, most schemes are hybrids, having both kinds of criteria to be satisfied at the same time.
- **Evaluation body**. Based on who produces the assessment, it can be distinguished in third party, second party or first party. Third party assessment means that the evaluator is independent from the product manufacturer, contractor, designer and specifier and has no financial interests or ties to the outcome of the assessment. Second party assessment refers to the case when an interested party, such as a trade association, performs the evaluation. First party

assessment takes place when the evaluation is coming directly from an organization that is associated with the entity making the claim or that benefits from the claim (Brilhante & Skinner 2015).

Figure 3-10 illustrates the described features.

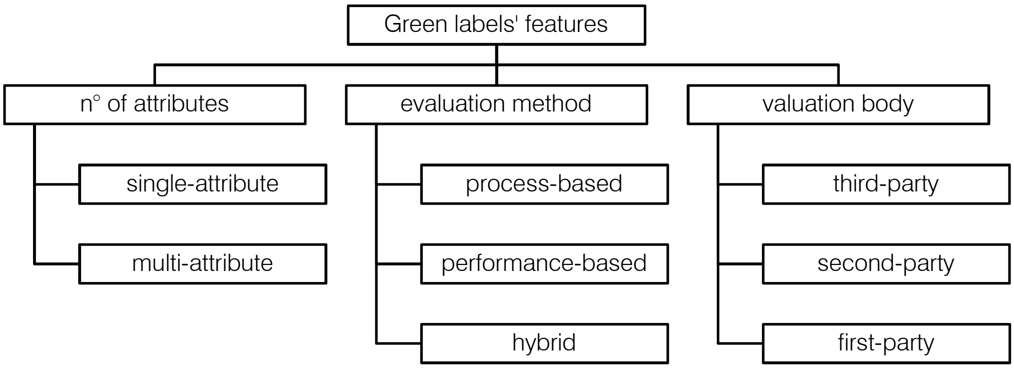


Figure 3-10: green labels' possible attributes

Despite the different characteristics that diversify the green labels, all certification schemes share five basic points, as follows (Houlihan Wiberg 2009; Brilhante & Skinner 2015):

- **Voluntary enrolment**. All green labels certification schemes in tourism industry are voluntary, they are based on the assumption that tourism operators have interest in being certified, according to their schemes, to obtain market advantages.
- **Logo**. All schemes provide a logo designed to be recognizable by consumers. The logo can be used only after achieving the certification. Many certification schemes provide different logos for a different level of total score achieved.
- **Compliance with international or national regulations**. All certification schemes require, at minimum, that tourism operators comply with local, national, regional and international regulations.
- **Assessment and auditing**. All certification schemes give logos based on assessment or auditing. This can be first partly, second partly or third-party auditors (this is considered the most reliable because it avoids any conflict of interest).
- **Fees**. All certification schemes foresee the payment of fees to achieve the certification. Fees revenue is used for advertising and administrational cost.

3.5.2 Hotel-related green labels under review

An initial online research gave an immense number of potentially available hotel-related green labels to be analyzed. By typing "green label hotel" as keywords in Google research engine, 6.870.000 results were found. To face the challenge, the researchers based the preliminary selection of labels on the analysis of the literature on the topic (Font 2002; Buckley 2002; Houlihan Wiberg 2009; Oom do Valle et al. 2012; Shi et al. 2016). Starting from the green labels mentioned in literature, a targeted online research was performed, aimed at collecting the necessary data for further shrinking the sample. The second-level selection was performed based on the labels features. Only multi-attribute criteria green labels were considered, in view of the fact that the scope of the study was to evaluate the weight of different items in the global rating, to better estimate the weight of energy efficiency in the labelling programmes. Additionally, the selection exclusively considered third-party certifications, as a green certification is considered more respected and trustable when an independent third party is responsible for conducting the product testing and awarding the certification (Font 2002; Bratt et al. 2011; Brilhante & Skinner 2015). The selection of green labels was also influenced by their "transparency", i.e. to which extent the standards and the processes for awarding the certification were transparent and open for examination. Among all the labels fulfilling these basic requirements, the final selection of the objects of a detailed review was based on their geographical competence. Both international and national green labels were considered and national labels were selected in order to cover all the main geographical zones in the world. The resulting list of green labels counts 19 voluntary green labels. Their geographical competence is illustrated in Figure 3-11.

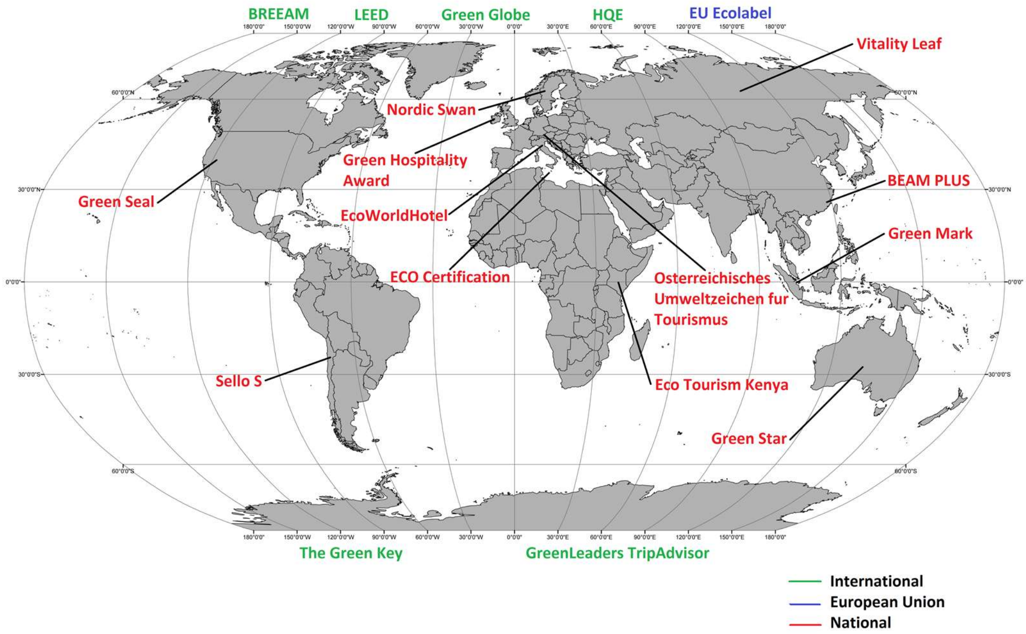


Figure 3-11: Geographical coverage of the selected green labels

The international green labels chosen were: Building Research Establishment Environmental Assessment Methodology (BREEAM), Leadership in Energy and Environmental Design (LEED), Green Globe, The Green Key, Haute Qualité Environnementale (HQE) and GreenLeader TripAdvisor. The latter is not as technical as the other labels studied, but it is taken into account because it is strictly related to the searching engine most used for hotel booking by consumers worldwide. For Asia, two certification schemes were selected: Green Mark, based in Singapore, and Building Environmental Assessment Method (BEAM PLUS), based in Hong Kong. Green Star is chosen for Australia and New Zealand, Green Seal for USA, Sello S for Chile, and Ecotourism Kenya for Kenya. As regards the areas of South America and Africa, two labels were chosen, respectively for Chile and Kenya, although other schemes were found. However, since the majority of the found green labels in those areas are not exhaustive, the most complete ones are selected for the analysis, as representative of the zones. As regards as the European Union, EU Ecolabel is the green certification scheme valid for all Members States. In addition, green labels of single countries or groups of countries in Europe were selected: Nordic Swan for North Europe, Österreichisches Umweltzeichen für Tourismum for Austria and Germany, ECO Certification for Malta, Vitality Leaf for Russia, Green Hospitality Award for Ireland, ClimaHotel and EcoWorldHotel for Italy. Even if the economy of the Mediterranean area is strongly dependent on tourism, there are not many completely exhaustive local green labels. As in the case of South America and Africa, Malta Eco Certification and EcoWorldHotel are selected as representative of the area.

3.5.3 Terms of comparison among green labels

Detailed data about each label were retrieved from the corresponding manuals, available online. Information derived for each label refer to: number of certifications; categories of environmental performance considered; energy efficiency requirements included; scoring method, validity period and price. Tables displaying these data are reported in Appendix A.

While number of certifications, scoring method, validity period and prices are parameters with univocal meanings and typically expressed by figures, categories of environmental performance and of energy efficiency requirements can vary a lot from label to label. Consequently, systematization of the collected information about environmental and energy performances was the preliminary step for a thorough understanding of labels' requirements and their coherent comparison. Based on this analysis, it possible to draft a list of the most common parameters taken into account in hotel green labels, as described in the following paragraphs.

Environmental performance categories

Building upon the environmental performance requirements analysed in the 19 labels, different categories of environmental performance were identified:

- **Energy Efficiency** (EE), focusing on energy management, energy efficient equipment and adoption of renewable energy sources.
- **Water Efficiency** (WE), considering both the reduction of clean water use and the management of exhaust water.
- **Sustainable Site** (SS), considering the connection between building and surrounding natural environment, focusing on the presence of green areas, the use of vegetation native species, the solar exposure, the use of the soil, etc.
- **Waste Management** (WM), focusing both on the reduction of waste production and on the increment of recycling rates.
- **Indoor Environmental Quality** (IEQ), considering thermal comfort, lighting, noise reduction and air quality.

- **Health & Wellbeing** (HW), considering all the daily products needed for the wellbeing of consumers, as toiletries, towels, local food and the extra services eventually provided to clients, as fitness centre, SPA, swimming pools, etc.
- **Materials & Resources** (MR), considering both the sustainability of raw materials and the percentage of recycled resources used during the construction phase.
- **Pollution** (P), considering the emissions of pollutants in air, water and soil, during the complete life cycle of the building.
- **Transport** (T), considering the reduction of vehicle distance travelled and encouraging the use of public transports and bicycles.
- **Communication/Education/Management** (CEM), considering both the empowerment of clients and staff through advertisement and training and the actual hotel administration.
- **Innovation** (I), considering advanced practices, new technologies used and design.

Due to their very diverse origins, every label has different scoring methods. To allow a comparison among different labels in terms of relevance of the listed categories on the overall evaluation of the environmental performance of each label, the relative weighting ($S_{w,X}$) of these categories was calculated as follow:

$$S_{w,X} = \frac{S_{i,X}}{S_{tot,X}} \times 100 \tag{3-1}$$

where,

- $S_{i,X}$ is the maximum score attributed by the green label X to the category of environmental performance I;
- $S_{tot,X}$ is the maximum total score attributed by the green label X to the hotel building.

Not all the listed green labels offered a clear division among these items to reach the total score; for these labels, it was not possible to calculate the average weights of the categories of environmental performance taken into account.

Energy Efficiency requirements

Specific object of investigation was then the level of detail of energy efficiency (EE) requirements. Based on the various terms detected in the EE performance category, 12 representative sub-categories were identified in order to make a comparison among labels:

- **Building Opaque Envelope**, that considers the thermal and architectural features of roofs, ceilings and vertical surfaces.
- **Building Transparent Envelope**, that considers the thermal and architectural features of windows and shading elements.
- **Energy Efficient Equipment & Control**; this category includes the installation of efficient electric equipment and HVAC systems, considering all the aspects related to heating, cooling, air conditioning and ventilation. The term control indicated the presence of HVAC control systems, based on temperature set points, minimum ventilation rates and relative humidity.
- **Domestic Hot Water** (DHW), that considers hot water generation and distribution.
- **Advanced Generation Systems**, that takes into consideration the presence of systems as district heating or cooling, heat pumps, cogeneration and heat recovery.
- **Energy Efficient Lighting & Automatic Control**; this category includes the adoption of efficient lighting systems and the use of automatic control, as daylight sensors and presence sensors.
- **Renewable Energy**, that considers the heat & power generation from green energy sources.
- **Minimum Energy Performance**, that evaluates the compliance with national and international regulations.
- **Energy Management**, that considers both the installation of Building Management Systems and the definition of a long-term management plan.
- **Energy Monitoring & Audit**; this category indicates the presence of a plan of energy tracking on annual or monthly basis and the implementation of periodic energy audits.
- **CO_2 Reduction**, that considers the reduction of emissions due to energy use: this voice accounts the emissions due to energy use and all the actions done at energy level in order to reduce them.

- **Efficient Wellness Centre Equipment**; this category groups the use of hand and hair driers with proximity sensors, sauna timer control and efficient heating systems for swimming pools.

Further attention was paid to the presence of minimum compulsory energy efficiency requirements. Green labels imposing minimum requirements force the hotel business to put into practice energy efficiency measures, therefore becoming realistic indicators of sustainability rather than a mere marketing tool. In case mandatory energy efficiency requirements are not in place, it is possible for a hotel to be labelled as “green”, even if completely skipping the energy performance issues.

3.5.4 Comparative analysis’ results and discussion

The comparative analysis of the features of the selected 19 labels allowed drawing some interesting considerations about their effectiveness in describing the environmental and energy performance of a hotel. First remarks deal with the availability of information open to public, tested during the online research performed. In general, international certification schemes were more transparent than the national ones. The online information research was smoother and all the data and requirements were available online, as well as support tools for stakeholders and consumers. With the progressive reduction of green labels’ geographical competence, the information on certifications appeared to be less exhaustive and complete. In many cases, these green labels were less transparent, since on the website the data were not published or not updated. Often, information was provided only after specific requests by mail or by registration. Moreover, in some national certification schemes the online material was available only in local language.

Coming to the direct comparison among different green labels, some issues arose. Indeed, a coherent comparison among labels can be done only in terms of number of certifications released. Specifically, these figures highlight that BREEAM, HQE and LEED (all international schemes) are the most widespread. Their open data availability, combined with a solid organizational structure that, among others, requires training courses for certifiers, certainly contribute to their wide diffusion. For all the other features reported in table, a straight evaluation based on comparison was not possible. First, all the studied schemes adopt different rating systems: levels, stars, percentages, points, leaves, etc. The average weighting proposed in equation (3-1) was the authors’ solution to overcome this mismatching.

Additionally, the classification of labels requirements into categories of environmental performance asks for a critical interpretation. Indeed, although the considered macro areas are similar (energy, water, waste, management and education), the green labels explore diverse sub-items and establish dissimilar requirements. For these reasons, the green labels are not comparable among each other, also in view of the fact that in literature it is not possible to find a conversion scale from one label to another. Not even fees and validity periods are immediately comparable. Each label accounts for different components in the total cost of their certification process and the validity period is closely linked with the payment of the fees.

These elements, together with the large amount of tourism certification schemes worldwide, contribute to the increase of consumers' confusion and indecision. Also from tourism operators' standpoint, it is challenging to understand which certification scheme could be more profitable. Keeping in mind the variety in terms of fees and validity periods, it is licit to infer that tourism operators would prioritize money-driven selection criteria, rather than environmental ones, when choosing a green label to display.

The role of Energy Efficiency requirements

Despite the inhomogeneous contents of different labels, their comparison still provides interesting insights on the role of energy efficiency in the certification schemes. In Figure 3-12 the share of labels that include the identified 11 categories of environmental performance are shown. From the graph, it is possible to notice that all the analysed certification schemes take into account Energy (EE) and Water Efficiency (WE). Other important features in the labels are Sustainable Site (SS), Materials & Resources (MR) and Communication, Education and Management (CEM), taken into account by more than 80% of the studied labels. Minor attention is addressed to Pollution (P), Transport (T) and Innovation (I), aspects considered by less than 50% of the green labels.

In Figure 3-13 the average weighting is exploited to compare the relevance that selected categories of environmental performance have on the total scores. Results show that Energy Efficiency is the most important category in the overall evaluation for 9 of the 15 labels where categories were identified, representing from 20% to 40% of the maximum score.

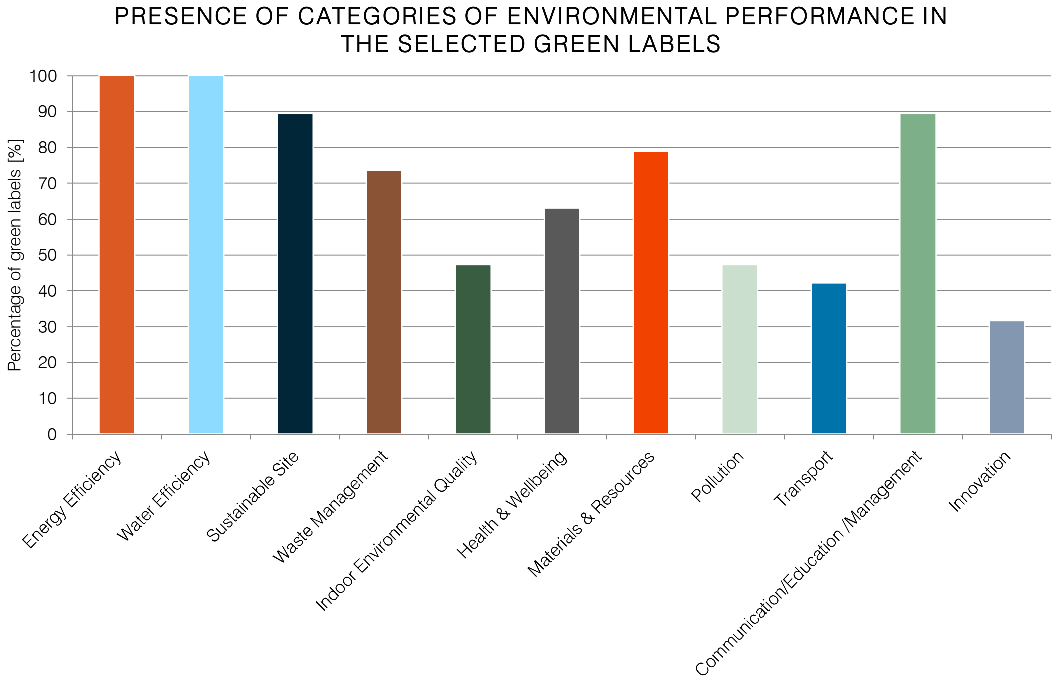


Figure 3-12: Categories of environmental performances in the selected green labels

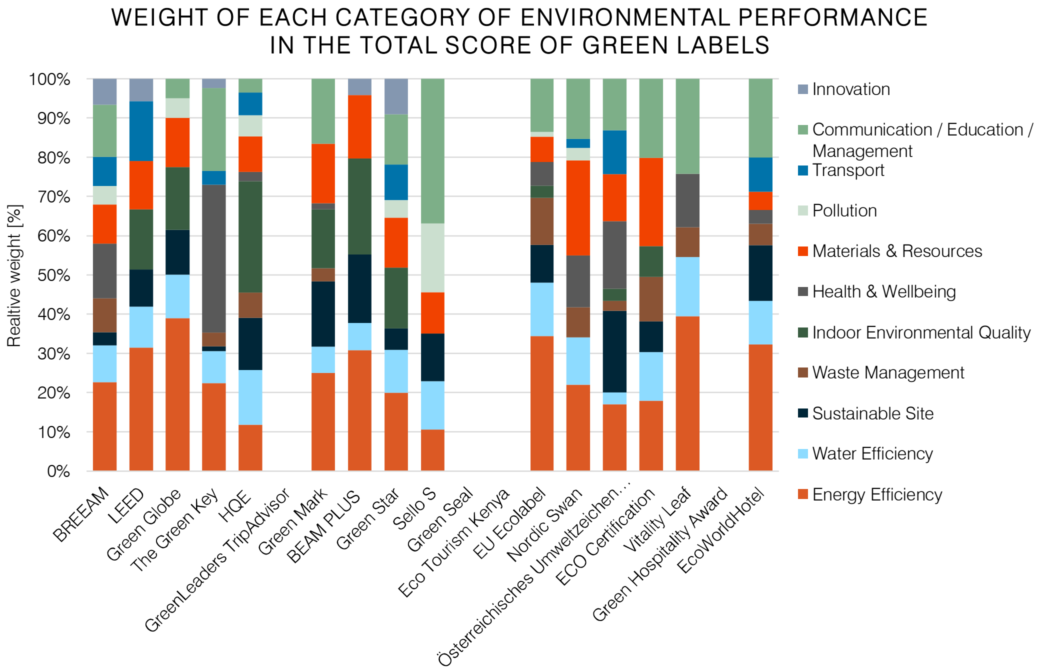


Figure 3-13: Relative weight of each category of environmental performances in the selected green label

The in-depth analysis of requirements dedicated to Energy Efficiency highlighted a variety of terms among the different labels, both in terms of actions required and in level of detail in their description. Figure 3-14 illustrates the number of green labels that include the representative sub-categories of energy efficiency described above; each radius represents one item, while the concentric polygons indicate the number of labels. This radar graph reports two lines: the orange one, representing the total number of green labels that include a specific item in the evaluation, and the black one, showing the number of labels that have that sub-category as a minimum requirement.

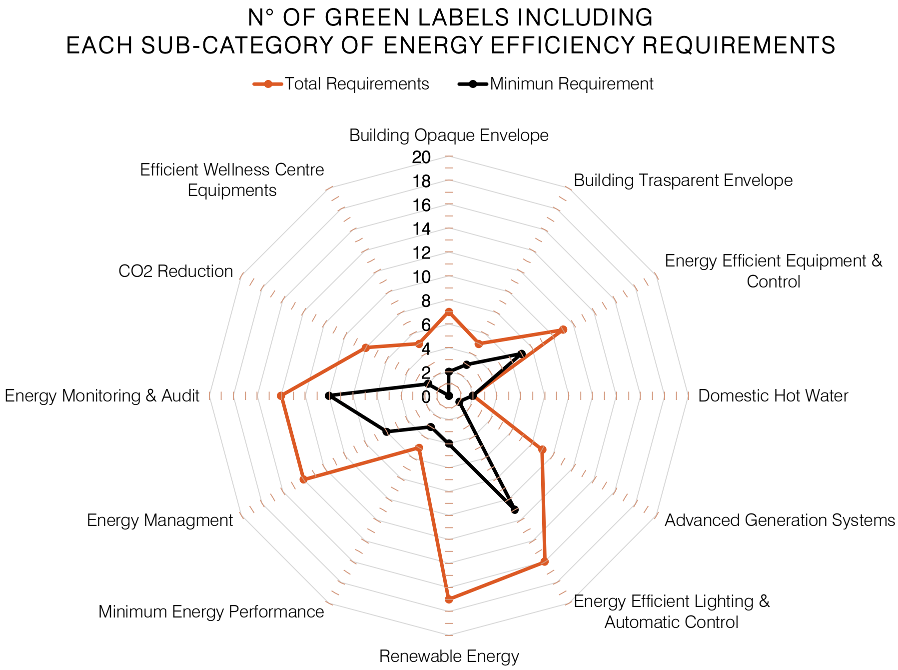


Figure 3-14: Mandatory and total sub-categories of energy efficiency requirements in the selected labels

The analysis of each sub-category of Energy Efficiency requirements revealed that almost all the studied green labels (17 out of 19) include Renewable Energy in the energy efficiency category of environmental performance, in line with the global renewable energy policies. However, only 4 labels out of 19 consider this sub-category as a minimum requirement. Besides Renewable Energy, the most common items in the various green labels are: Energy Efficient Lighting and Control (present in 85% of analysed green labels), Energy Management and Energy Monitoring (75%). It is worth noting that these measures are the least expensive in terms of economic investment, they require minor technical interventions and they have a high energy and economic saving potential in the short term. Moreover, they can be implemented without interrupting hotel operations. Energy Efficient Lighting & Control and Energy Monitoring & Audit are also the most common minimum requirements (present respectively in 11 and in 10 green labels out of 19).

Another interesting outcome is that Building Transparent Envelope, Minimum Energy Performance and Efficient Wellness Centre Equipment (all present in 25% of selected green labels) and DHW (10%) are the least common energy efficiency sub-categories in green labels. The great relevance that requirements related to hotels glazing, energy and hot water consumptions have on hotels energy performances may clash with these findings. However, it must be recalled that most of third-party certifications require the fulfilment of mandatory local energy requirements as a prerequisite for applying to the green label. Efficient Wellness Centre Equipment is the only voice not having minimum requirements, even if these extra services are usually energy intensive. However, coupling good management plan with efficient equipment can help reducing global energy consumption of these services, while answering to more common EE requirements.

Only 40% of green labels includes CO_2 Reduction between the terms of energy efficiency. Among them, only 10% considers this entry as a minimum requirement. Of course, CO_2 reductions are implicit by-products of all the EE related measures. However, given the international attention nowadays paid to dangerous emissions, the relevance of this sub-category of requirements should grow and include numerical values for reductions. These limit values should guide the implementation of EE measures. Indeed, it is important to note that, at present, even when the CO_2 emission reductions are treated in the certification process, the labels do not clearly quantify the amount of avoided CO_2 emissions or do not express limit values of emissions that hotels should respect.

As a general remark, the impossibility to compare different labels, denounced above, is transposed to the Energy Efficiency category level. Due to the highlighted diversity in tackling Energy Efficiency in the different green labels, it is difficult to perform a comparison between them. Moreover, none of the certification produces an energy indicator able to quantify the effective energy or carbon savings in the accommodation structures. The various types of EE measures required and the mix of evaluation methods (process vs. performance-based) and indicators across all labels, dampen the informative contents of any comparison among green labels.

3.6 Key findings

The research contribution of this chapter refers to the comparative analysis of selected hotel-related green labels, with the specific aim of investigating their ability to inform about the energy performance (energy use and CO_2 emissions) of accommodation structures. The comparison highlighted that energy efficiency is the most quoted category of requirements and has the heaviest impact on the total score among the investigated labels. Within the wide spectrum of energy efficiency-related requirements, the systematic monitoring of the hotel energy performances and the implementation of low-capital/short pay-back-period measures were the most mentioned in terms of minimum energy requirements. Indeed, they allow to rapidly obtain high energy savings with low annoyance for guests. Conversely, CO_2 emissions requirements were considered by a limited number of labels. Additionally, none of them imposed limits on emissions. From a broader perspective, the research pointed out the impossibility of an even evaluation of different labels. For instance, although all the selected green labels include the energy efficiency category, not all the certification schemes are equally detailed and they miss common base requirements. Moreover, since green labels do not provide numerical results expressing the effective energy/carbon savings of an accommodation, it is difficult to compare hotels and to select the more efficient ones.

This information gap questions the role of green labels as tools to effectively reduce the energy related CO_2 emissions, supporting Houlihan Wiberg's findings (Houlihan Wiberg 2009). In view of effectively reducing the energy use and related CO_2 emissions of hotel buildings, different valuation methods should be tested. In this regard, next chapter displays examples of application of the cost-optimal methodology, promoted at the European level to define minimum energy requirements for buildings, as a tool to define financially convenient energy reduction strategies for hotel businesses.

Chapter 4

4. Cost-optimal methodology applied to hotels

4.1 Overview

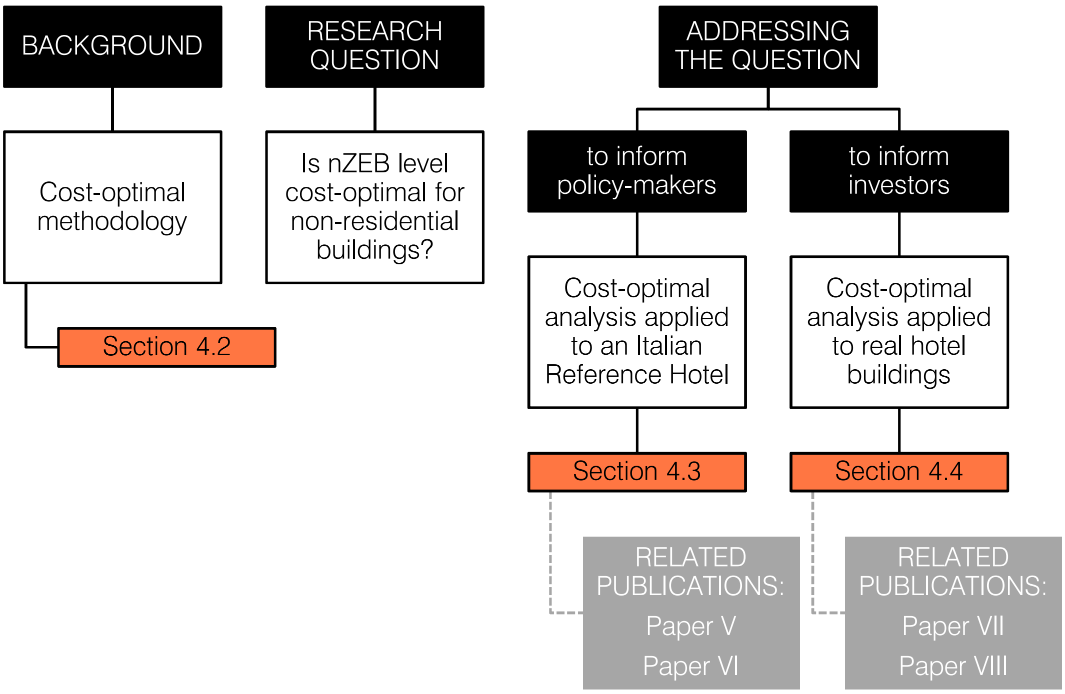


Figure 4-1: Schematic summary of Chapter 4's objectives and contents

The background for this piece of research lies in the on-going transposition of the EPBD recast in Member States (MSs). By January 2021 all over Europe new private buildings will have to comply with nationally defined NZEB standards. Accordingly, most of MSs have now endorsed EU requirements in their regulations and set numerical indicators for new and existing buildings aiming to reach the NZEB level (BPIE 2015). In the EU view, these national figures should also represent the cost-optimal level of energy performance from 2021 on, meaning that NZEB design options should be those leading to the lowest global cost during the estimated lifecycle of buildings. However, the envisaged full match between cost-optimal and NZEB energy performance level remains an open issue. In particular, while cost-optimal and NZEB studies have flourished in recent years for residential buildings – e.g. (Becchio, Dabbene, et al. 2015; Ferreira et al. 2016) – and office buildings – e.g. (Pikas et al. 2014; Congedo et al. 2015) – other non-residential categories have been rarely investigated. Indeed, MSs are allowed to derive minimum level of energy performances for the whole non-residential sector from the application of the cost-optimal methodology to basic reference buildings for offices (one RB for new buildings and minimum two RBs for existing buildings), if other specific non-residential buildings minimum requirements do not exist in their national regulations (European Commission 2012a). Due to the calculation efforts that the cost-optimal methodology requires, recalled in section 4.2, and to the lack of representative/reliable/detailed data about the non-residential sector, this strategy is the most widely used. Nonetheless, given the broad variation of building features among the non-residential sector, such an approximation is misleading in deriving cost-optimal level of energy performance for non-residential categories other than office buildings.

To serve this cause, the research question addressed in this chapter is:

Is NZEB level cost-optimal for non-residential buildings?

The matter was explored by proposing retrofit solutions for hotel buildings. Hotels are representative examples of a wide range of non-residential multi-functional buildings and are identified in EPBD recast as a specific building category to be considered in the definition of minimum energy performance requirements. Specifically, Italian hotels were analyzed, as they represent a relevant share of the EU accommodation building stock (18%) and because of the availability of numerical NZEB requirements in the Italian legislation to refer to.

On the one hand, section 4.3 presents the full development of the cost-optimal methodology for an Italian Reference Hotel, as recommended by the European Commission, in order to inform policy-makers about how demanding the forthcoming market transition towards an energy efficient building stock will be for the accommodation sector. Coherently with the specific nature of the building category under investigation, the traditional valuation procedure was enriched with comfort-related considerations. On the other hand, in the framework of the PhD research, the cost-optimal methodology was used as decision-making tool in the pre-feasibility phase for hoteliers willing to retrofit their structures. Retrofit options were proposed for existing hotel buildings, to inform investors about feasible and convenient energy efficient design solutions. Results of the case-specific studies are reported and critically discussed in section 4.4.

Figure 4-1 summarizes the chapter's objectives.

4.2 The cost-optimal methodology

The concept of cost-optimality was introduced in the EPBD recast as a result of several EU consultations highlighting the significant potential for cost-effective energy savings in the buildings sector (BPIE 2010). With the EPBD recast, for the first time economic considerations were included in an official document setting energy efficiency requirements: Article 4 of the EPBD recast states that MSs shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels; Article 5 requires that MSs calculate cost-optimal levels of minimum energy performance requirements for buildings and building elements using a comparative methodology framework to be established by the Commission (European Parliament 2010).

To guide Member States in their national cost-optimal calculations, in 2012 the Commission published delegated Regulation No. 244/201212 (European Commission 2012a) and its accompanying guidelines (European Commission 2012b). In these documents the comparative methodology framework is detailed in view of addressing the national authorities to develop cost-optimal minimum energy performance requirements. Cost-optimal analysis is made-up of 6 main steps, to be ideally applied to each of the 9 building categories listed in the EPBD recast (single-family houses, apartment blocks, offices, educational buildings, hospitals; hotels and restaurants; sports facilities, wholesale and retail trade services buildings; other types of energy-consuming buildings). Based on the guidelines' contents, the phases of the analysis are here briefly recalled:

I. **Definition of the Reference Building (RB)**. RBs are the object to which the cost-optimal analysis is applied. Hence, they "ought to reflect as accurately as possible the actual national building stock so that the cost-optimal methodology can deliver representative calculation results" (European Commission 2012b)
II. **Identification of Energy Efficiency Measures**. MSs must define the energy efficiency measures (EEMs) to be applied to the selected reference building. These measures should include solutions regarding envelope, systems and renewable energy sources. The combined effect of these solutions on the building energy performance should be tested by defining packages/variants.
III. **Calculation of Primary Energy Consumption**. The objective of the calculation procedure is to determine the annual overall energy use in terms of primary energy, including the typical building's operational uses for heating,

cooling, ventilation hot water, lighting and, possibly, equipment. CEN Standards are the recommended references for these calculations, which should be performed involving first the calculation of final energy needs for heating and cooling, then the final energy needs for all energy uses, and thirdly the primary energy use. Three different calculation methods are possible: a monthly quasi-steady state calculation method, a simple hourly calculation method and a detailed simulation method. This last method is the more accurate, but it is also the more complex and incorporates several disciplines to obtain a precise finish product.

IV. **Calculation of the Global Cost**. Global cost calculation results in a net present value of costs incurred during a defined calculation period. For each EEM, the initial investment, the sum of the annual costs for every year and the final value are considered, all with reference to the starting year of the calculation period. Going in more detail, only investment costs of measures that are related to the energy performance of a building are taken into account. Annual costs include costs for energy carriers that cover the demand for space heating and cooling, ventilation, domestic hot water, lighting and appliances, including auxiliary energy. Income from produced energy (e.g. photovoltaic systems) can be subtracted from the costs for energy carriers. Annual costs also include operational costs, maintenance costs and costs for periodic replacement. To ensure a lifecycle perspective, final values are taken into consideration for components with lifetimes that are longer than the chosen calculation period. For components that have a shorter lifetime than the chosen calculation period, the replacement of the component needs to be accounted. Investment costs, running costs, energy costs must be context-based, while the European Standard EN15459 (CEN 2007c) is a precious reference for maintenance and replacement costs and final values. In case of cost calculation performed from a macro-economic perspective, cost of greenhouse gas emissions is included in the calculation.

V. **Derivation of Cost-optimal levels**. Based on the calculations of primary energy use (step III) and global costs (step IV) associated with the different packages/variants of measures (step II) assessed for the defined Reference Building (step I), the cost-optimal graphs can be drawn. This describes primary energy use (x-axis: kWh/(m^2y)) and global costs (y-axis: €/m^2) of the different solutions. A measure or package/variant of measures is cost-effective when the cost of implementation is lower than the value of the benefits that result, taken over the expected life of the measure. The cost-optimal result represents that retrofit action or combination of actions that minimized the global cost. From the number of EEMs assessed, a specific cost curve can be developed; it represents the lower border of the area marked by the data points of the different EEMs. The lowest point of the curve represents the economic optimum for a combination of packages. Its position on the x-axis automatically gives the cost-optimal level of minimum energy performance requirements.

VI. **Sensitivity analysis**. Assumptions on key parameters used to derive cost-optimal levels of energy performance can have a significant impact of the results of the analysis, as these parameters may vary during the period of calculation. Hence, some sensitivity analyses must be undertaken by the MSs. This analysis must study at least a different price scenarios for all energy carriers of relevance in national context, plus at least two scenarios each for the discount rates to be used for the macroeconomic and financial cost optimum calculations.

Since the publication of these documents, a plethora of studies have been conducted to critically analyze and apply the cost-optimal methodology to several contexts, often trying to relate cost-optimal levels of energy performance with the and NZEB target (Atanasiu 2013; Boermans et al. 2015; Congedo et al. 2015; Pikas et al. 2014). Indeed, the EPBD recast also requires MSs to set NZEB targets that will be mandatory for all new buildings from 2021, meaning that minimum (cost-optimal) and NZEB requirements should overlap by that time. Additionally, in recent years the cost-optimal methodology was proposed by some studies as decision-making process in pre-feasibility phase for real buildings (Barthelmes et al. 2014; Becchio et al. 2016; Congedo et al. 2016). Cost-optimal levels identified at national scale may not be cost-optimal for private investors. Studying the proper combination of energy efficiency measures pursuing economic effectiveness and compliance with national requirements can provide interesting insights to investors.

Building upon these considerations, in the followings of the chapter cost-optimal methodology is applied to hotel buildings in Italy both from the national authorities' standpoint (i.e. for a Reference Hotel) of and from private investors' standpoint (i.e. for real buildings).

4.3 Cost-optimal analysis for a Reference Hotel

In Italy, national level cost-optimal studies have been developed as a preliminary step towards the review the energy-related regulations in place in 2010, which were compliant with the previous EPBD. As summarized in a dedicated ENEA report (Corrado et al. 2013), the cost-optimal methodology was applied to the Italian context by defining eighteen residential reference buildings, representing new and existing single family houses, small and large apartment buildings in two representative climatic zones, and six office reference buildings, depicting typical new and existing buildings configurations in the same two climatic zones. Residential reference buildings were defined based on the outcomes of the EU project TABULA; office reference buildings resulted from ENEA studies. The number of EEMs and packages considered varied from reference building to reference building and their energy performances were calculated according to Italian standards UNI TS part I, II, III and IV. The corresponding global cost, instead, was obtained by following the EU standard UNI EN 15459. The cost-optimal level of energy performance resulting from this study confirmed that the mandatory minimum energy requirements in force at the time for the study had room for improvement. These findings were the starting point for setting new building minimum energy requirements, in place since 2015.

In this section, instead, the cost-optimal methodology is fully developed for analyzing the energy use reduction potential of the Italian hotel sector, which was out of the interest of these early cost-optimal studies. The goals are (a) the definition of the cost-optimal level of energy performance for a hotel representative of the accommodation stock and (b) the assessment of the gap between cost-optimal and newly set NZEB level of energy performance in this building typology. Sections 4.3.1 – 4.3.3 are devoted to describe in detail the Reference Hotel, original outcome of this thesis, and proposed to the academic community through the author's Paper II and Paper V, enclosed to the dissertation. Sub-section 4.3.4 is dedicated to derive the nearly zero energy target for the Reference Hotel as imposed by the Italian transposition of the EPBD recast. Sections from 4.3.5 to 4.3.10 retrace the phases from II to VI of cost-optimal methodology. Finally, section 4.3.11 complements the methodology with comfort-related considerations, in order to investigate the effects of retrofit measures on guests' thermal sensations. Part of the outcomes presented in sections 4.3.4 to 4.3.5 were also published in Paper VI, attached to the PhD thesis in Part II.

4.3.1 Definition of an Italian Reference Hotel

According to the EPBD recast, a Reference Building "represents the typical building geometry and systems, typical energy performance for both building envelope and systems, typical functionality and typical cost structure in the Member State and is representative of climatic conditions and geographic location" (European Parliament 2010). This definition points out the different scale at which Reference Buildings can be used. At the building scale, Reference Buildings are exploited to define benchmark values and achievable minimum energy performance requirements. At the district/urban/regional scale, they represent archetypes, upon which engineering bottom-up energy models of the building stock can be based. Hence, in view of creating a Reference Building representative of the Italian hotel stock and of enriching the EU Reference Buildings library, the 3-steps modeling method for Reference multi-functional Buildings proposed in Section 2.5 was applied to create a Reference Hotel.

Step 1 - Definition of the relevant energy uses

As recommended in EPBD recast, the energy uses considered for the typical functions of a Reference Building are heating, cooling, ventilation, hot water, lighting and appliances used to maintain the indoor standard comfort condition. Building on these premises, the typical energy use of a hotel can be identified with the energy used to maintain indoor environmental comfort conditions related to hosting functions (i.e. for guests). Zones covering these functions are typically guestrooms, receptions, halls, offices, dining areas, meeting rooms. Extra functions, instead, are all those additional services offered to guests, such as kitchen, fitness area and laundry. In thermal zones where these activities are in place, the share of the overall energy use devoted to maintaining a comfortable indoor environment is typically lower than the amount of energy needed to provide the service. In Table 4-1 a list of the most common zones of a hotel building and their categorization in typical and extra functions is given.

Table 4-1: Typical and extra functions in hotel buildings

Function	Zones included
Typical	Guest-rooms, Hall, Reception, Offices, Dining rooms, Meeting rooms, Service rooms
Extra	Kitchen, Laundry, Spa, Fitness area, Swimming pool, etc.

Step 2 – Definition of sub-categories

Sub-categorization of a building category, despite not mandatory for MSs, is suggested in the EU Regulation (European Commission 2012a) as a way to define different Reference Buildings, or the most representative one, in case the building category under investigation is made up of a very diverse stock. Hotel buildings well depict a highly-fragmented building stock, where design and operation are very dependent from the target guests. Therefore, a sub-categorization of the Italian hotel stock was proposed in order to focus on the most relevant share of buildings with similar features. Sub-category parameters were selected based on literature, and classes for each parameter for the Italian context were derived from experts' assumptions and statistical data. Relevant categories for hotel buildings in terms of typical functions and their justifications are here given:

- **Climatic area**. Main physical parameter deeply influencing the energy use of all building types, it is suggested as sub-category at the EU level (European Commission 2012b) and by the relevant literature related to the creation of benchmarks for the hotel stock (Pieri et al. 2015; Farrou et al. 2012; Boemi et al. 2011). Italy is formally divided in 6 climate zones, classified from A to F according the increasing Heating Degree Days (HDD). Nonetheless, in order to avoid excessive fragmentation, in this study the considered climatic zones refer to those used for Italian building typologies developed in the framework of Tabula project (Corrado et al. 2014). The classification is therefore based on experts' assumption.
- **Building age**. Physical parameter common to all building types, it is suggested as a driver in defining sub-categories by the European Commission (European Commission 2012b), as it mirrors quite accurately the building geometry and properties of the building plant-system. Building age classes were taken from the Italian outcome of Tabula project (Corrado et al. 2014). Despite the report only deals with residential buildings, the existing Italian hotel stock is

considered by experts very similar to the residential building stock in terms of geometry and construction typology.

- **Hotel size**. Physical parameter mentioned as subcategory in EU Guidelines (European Commission 2012b). In the specific case of hotels, size is usually expressed in terms of number of beds. Pieri et al. (Pieri et al. 2015) elected hotel size (both in terms of number of beds and floor area) as a significant variable in their analysis of the hotel stock and Boemi et al. (Boemi et al. 2011), based on statistical data, defined typical hotels for different sizes (small, medium, large). Partition in classes of size is typically based on statistics. In the specific case of Italian hotels, size classes are provided in terms of number of guestrooms by the national institute of statistics (Istat).
- **Hotel category**. Parameter specific for accommodation structures, it is expressed through the "stars" classification. Indeed, the number of stars attributed to a hotel implies different minimum services offered to guests, which affect the energy consumption of the building. Pieri et al. (Pieri et al. 2015), in their analysis of the Greek hotel stock, defined stars as a potential factor of differentiation. Beccali et al. (Beccali et al. 2009) assumed the definition of classes of hotels based on their star classification as a preliminary step of the analysis of the Sicilian building stock.
- **Hotel opening period**. Operational parameter related to the hosting functions that has the highest impact on hotels annual energy use. Indeed, Farrou et al. (Farrou et al. 2012) differentiated between hotels with annual and seasonal operation, in their proposal of a hotel classification based on energy use data. The classification of this parameter is suggested in the RSE report 162 (Aprile 2009), in which an Italian hotel market segmentation analysis pointed out the most common opening period options.

Table 4-2 shows the obtained sub-categorization matrix and, in <u>underlined types</u>, the classes of parameters identifying the sub-category of hotel building selected for the development of the Reference Building model.

Table 4-2: Sub-categories and related classes for the definition a Reference Hotel

Sub-Cat.	**Classes**							
Climatic Area	Alpine (HDD <3000)			Middle (HDD 2100-3000)		Mediterranean (HDD >2100)		
Building Age	… - 1900	1901 - 1920	1921 - 1945	1946 - 1960	1961 - 1975	1976 - 1990	1991 - 2005	2006 - …
Hotel Size	Small (≤24 guestrooms)			Medium (25-99 guestrooms)		Large (≥100 guestrooms)		
Hotel Category	1*		2*	3*		4*		5*
Opening period	All year			Summer		Winter & summer		

The study focused on the Italian Middle climatic zone. In this zone a medium size, 3-stars hotel, open all year and built between 1921-1945 was selected as the subcategory of Reference Hotel to be developed, because:

- in the Italian middle climatic zone (e.g. Turin, Milan), urban hotels devoted to business and cultural tourism - therefore open all year - are representative of an important share of the accommodation market (Aprile 2009);
- 3-stars hotels represent the highest share of businesses (45%) and beds (43%) of the Italian stock (Istat 2014);
- medium size hotels, more common in the urban contexts, are the 42% of businesses and 56% of guests' beds of the Italian hotel offer (Istat 2014);
- hotel businesses increased constantly from 1930 onwards (Becheri et al. 2014). Hotels built between 1921 and 1945 are taken as example of early stage buildings asking for deep retrofit actions.

Based on experts' assumptions, in this hotel type the most common services offered to guests are kitchen and fitness area.

Step 3 – Application of the modelling method

The modelling method proposed by Corgnati et al. (Corgnati et al. 2013) was applied for describing the features of the selected sub-category of Reference Hotel, and of the coupled extra services – kitchen and fitness area. Hence, details for four sections of parameters – form, envelope, system and operation - were retrieved from statistical data and/or experts' assumptions. As explained by Corgnati et al. (Corgnati et al. 2013), based on the information sources exploited to collect information of each section of parameters, RBs can be classified in Example, Real and Theoretical Reference Buildings. The modelling approaches applied to build the Italian Reference Hotel were the Example building and the Real building ones, based on experts' assumption and real data respectively. The detailed description of the model features for each section of parameters (form, envelope, system, operation) is reported in the following paragraphs.

4.3.2 Detailed description of the RH

Form

Form data were derived from a real building representative of the selected hotel sub-category. The internal layout of the selected hotel is shown in Figure 4-2 and Table 4-3 reports its main records and geometric data.

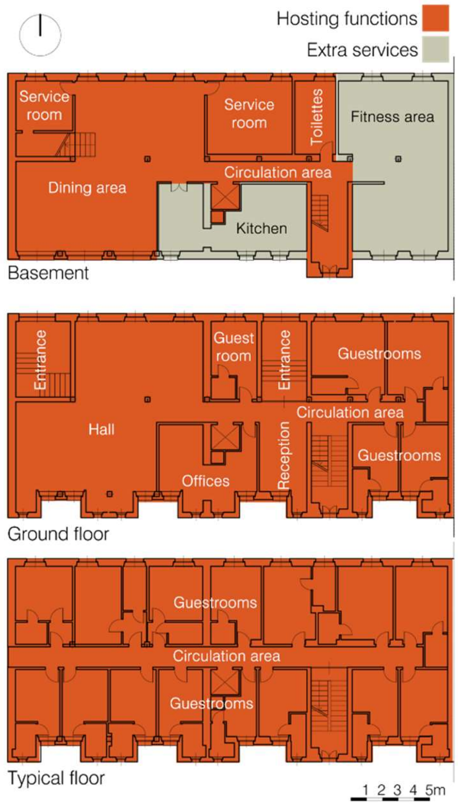


Figure 4-2: RH internal layout

Table 4-3: RH main features about form

	Metadata	Unit	Data
ANAGRAPHICS	Building type		Hotel
	Stars		***
	Year of construction/conversion to hotel		1933/1983
	Hotel type		urban
	Services to guests		Fitness area
			Breakfast (7:00-10:00/10:30)
			Reception (7/24)
	Guestrooms		49
	Average Guestroom Area	m^2	21
	Beds		95
	Average occupied rooms/day		18
	Average guests/day		27
FORM	Gross Area	m^2	2117
	Gross Volume	m^3	6433
	Conditioned Area	m^2	1700
	Gross Conditioned Volume (V)	m^3	5951
	Floors		5 (4 + basement)
	Average Gross Area per Floor	m^2	423
	Gross Roof Area	m^2	375
	Orientation		S-N
	N° of Façades		3
	Façades Total Area	m^2	1379
	Conditioned Surfaces Total Area (S)	m^2	1681
	Aspect Ratio (S/V)		28%
	Façades (above ground) Total Area	m^2	1275
	Opaque Façades Area	m^2	1059
	Glazed Façades Area	m^2	216
	Window/Wall (above ground) Ratio		17%

Envelope

In Table 4-4 thermal properties of the existing opaque envelope are briefly presented, while the detailed stratigraphy is given in Appendix B. Envelope layers were defined based on the real building site visits, while their thermal performances were derived from the corresponding data provided by TABULA project (Corrado et al. 2014). Glazed envelope properties, obtained with the same approach, are presented in Table 4-5.

Table 4-4: RH main features about opaque envelope

RH opaque envelope component			**TABULA** (Corrado et al. 2014) **corresponding component**	
	Thick. [m]	**U-value [W/m²k]**	**Description**	**U-value [W/m²k]**
Ext. Wall	0,43	1,1	Hollow wall brick masonry (40 cm)	1,1
Ext. Wall 1	0,23	0,8	Hollow brick masonry (25 cm), low insulation	0,8
Semi Exp. Wall	0,42	1,1	Hollow wall brick masonry (40 cm)	1,1
Pitched Roof	0,29	0,7	Flat roof with reinforced brick-concrete slab, medium insulation	0,7
Semi Exp. Ceiling	0,26	0,7	Ceiling with reinforced brick-concrete slab, medium insulation	0,7
Ground Floor Basement	0,34	2,0	Concrete floor on soil	2,0
Int. Wall	0,11	2,3	-	-
Int. Floor	0,29	0,7 (1,62 before finishing layer)	Ceiling with reinforced brick-concrete slab	1,65
Int. Floor 1	0,28	1,4 (1,62 before finishing layer)	Ceiling with reinforced brick-concrete slab	1,65

Table 4-5: RH main features about glazed envelope

RH glazed envelope component	**TABULA** (Corrado et al. 2014) **corresponding component**	**g-value**	**U-value [W/m²k]**
Window 1	Single glass, metal frame without thermal break	0,85	5,7
Window 2	Single glass, wood frame	0,85	4,9
Door	Glass and metal door (thermally improved)	0,75	3,8

System

The HVAC system of the Reference Hotel is made up of a centralized heating system, fueled by three condensing boilers and with cast-iron water radiators as terminal units, and of a centralized cooling systems, with an air-cooled chiller and splits. A schematic configuration of the system is given in Figure 4-3. The presented configuration was modelled following the “real building” approach. The RSE report on Italian hotel buildings confirmed the modeled system as representative of studied sub-category of hotels (Aprile 2009).

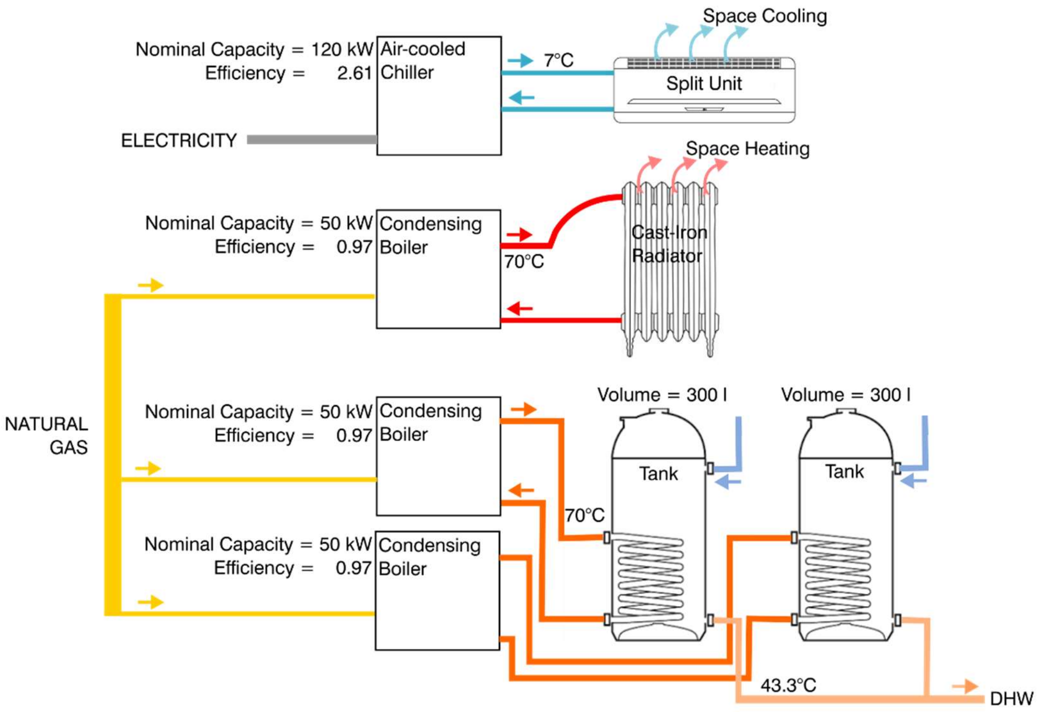


Figure 4-3: RH system scheme

Operation

Operational data were derived from national and international standards and literature, in order to be representative of a wide sample of hotels within the selected sub-category. National standards were preferred. When Italian input data were not available, they were replaced by data coming from EU standards. When both national and EU level input data were missing, pieces of information provided by US Department of Energy (Deru et al. 2011) were used.

Operational data include information about the building location, occupancy patterns, ventilation rates, installed powers and schedules. Dealing with location, for the purpose of the energy calculations the building was located in a central, densely built area of Turin. Turin, with its 2617 Heating Degree Days, perfectly represents the Middle Climatic Zone, in which the RH subcategory under consideration is located. Indoor thermal conditions were set based on EN15251 I Comfort Category (CEN 2007b), in order to comply with the high level of expectation that hotel guests typically have in terms of comfort. Thus, operative temperature set-points for heating and cooling were set respectively 21°C during occupied hours from October 15th to April 15th, and 25,5°C during occupied hours from April 15th to October 15th. The duration of the heating season (Oct. 15th – April 15th) was retrieved from Italian regulation (Presidente della Repubblica 1993). Occupancy, lighting, equipment and ventilation design values are summarized in Table 4-6, while Figure 4-4, Figure 4-5, Figure 4-6, Figure 4-7, display the occupancy, lighting, equipment and set-points schedules respectively.

Table 4-6: RH operation design values

Thermal Zones	**Design values**			
	Occupancy	**Lighting**	**Equipment**	**Ventilation**
Fitness area	0,2 pers./m^2 (+)	14,74 W/m^2 (++++)	11,5 W/m^2 (++++)	0,0165 m^3/(s·person) (+)
Toilettes	1 pers. (\)	10 W/m^2 (++)	10,76 W/m^2 (++++)	8 h^{-1}(+)
Service room	-	4,84 W/m^2 (++++)	16,1 W/m^2 (\)	-
Dining area	0,6 pers./m^2 (+)	10 W/m^2 (++)	-	0,01 m^3/(s·person)(+)
Stairs & corridors	-	9,25 W/m^2 (++++)	-	-
Kitchen	9,26 m^2/pers. (+++)	10 W/m^2 (++)	13450 W (\)	0,0165 m^3/(s·m^2)(+)
Elevator	-	-	2000 W (\)	-
Offices	0,06 pers./m^2 (+)	13 W/m^2 (++)	10 W/m^2 (++)	0,011 m^3/(s·person)(+)
Hall	0,2 pers./m^2 (+)	10 W/m^2 (++)	15,4 W/m^2 (++++)	0,011 m^3/(s·person)(+)
Reception	0,06 pers./m^2 (+)	13 W/m^2 (++)	10 W/m^2 (++)	0,011 m^3/(s·person)(+)
Entrance	-	9,25 W/m^2 (++++)	4 W/m^2 (++)	-
Guestrooms	0,05 pers./m^2 (+)	10 W/m^2 (++)	4 W/m^2 (++)	0,011 m^3/(s·person)(+)

Note: Reference: (\) Real building; (+) Reference: UNI 10339 (CTI 2005); (++) Reference: EN 15232 (CEN 2007a); (+++) Reference: NCM library ((Department for Communities and Local Government 2008); (++++) Reference: DOE Reference hotel model (Deru et al. 2011)

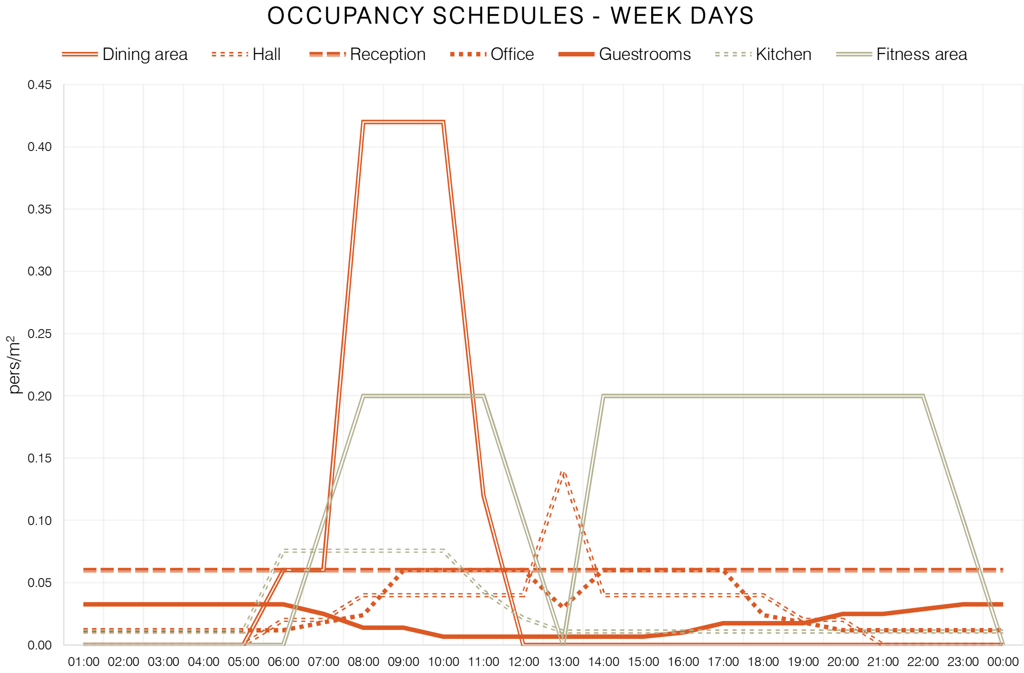


Figure 4-4: Occupancy schedules of the RH. Weekend schedules have very similar patterns

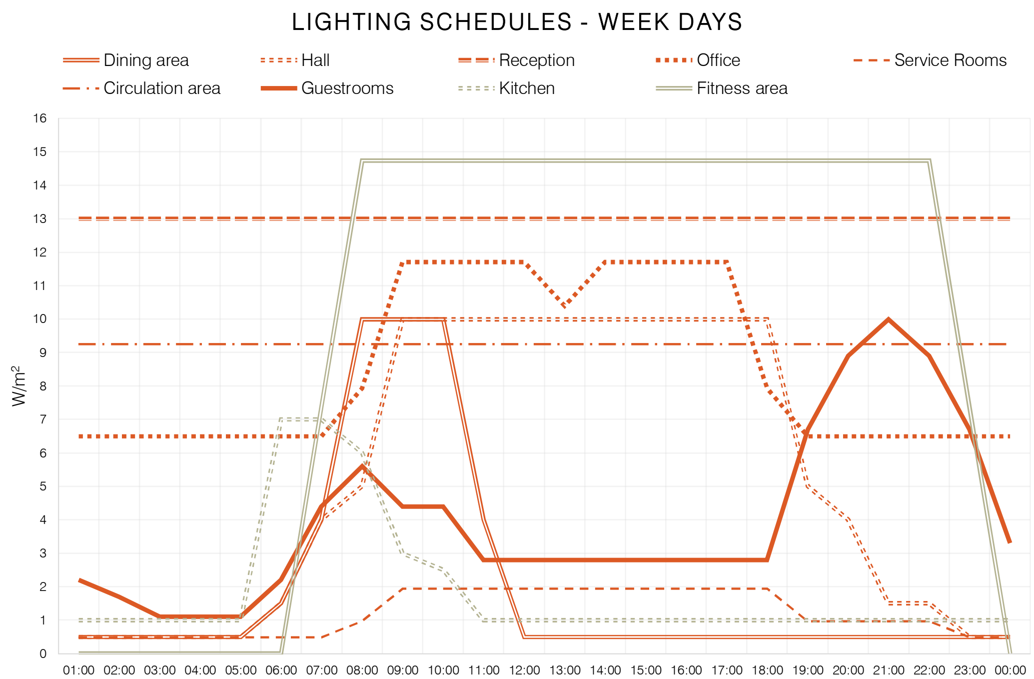


Figure 4-5: Weekdays lighting schedules of the RH. Weekend schedules have very similar patterns

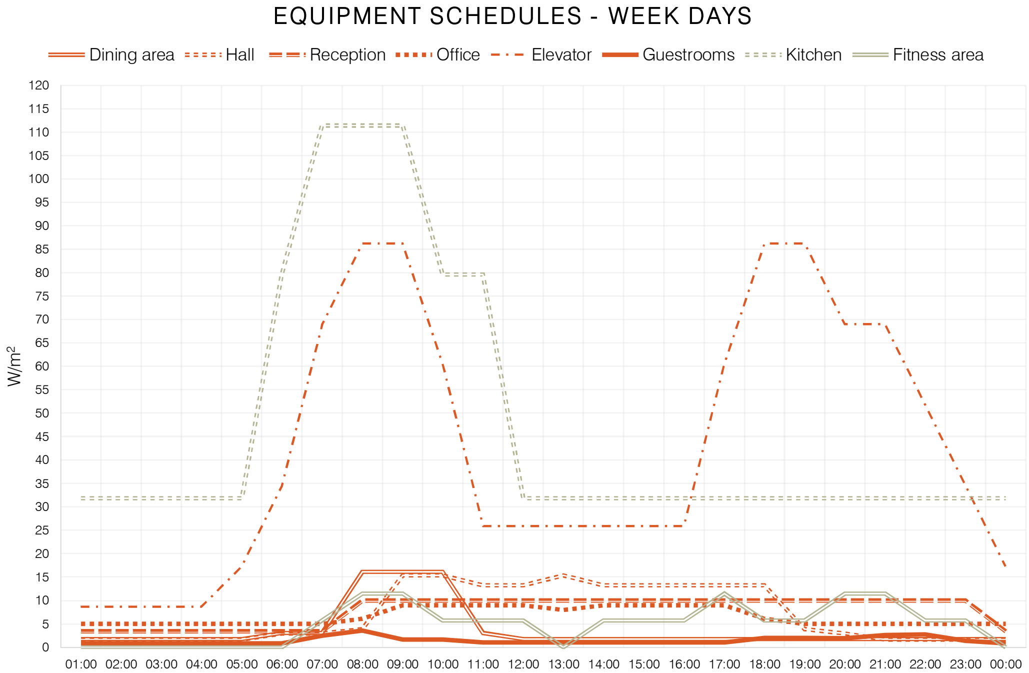


Figure 4-6: Weekdays lighting schedules of the RH. Weekend schedules have very similar patterns

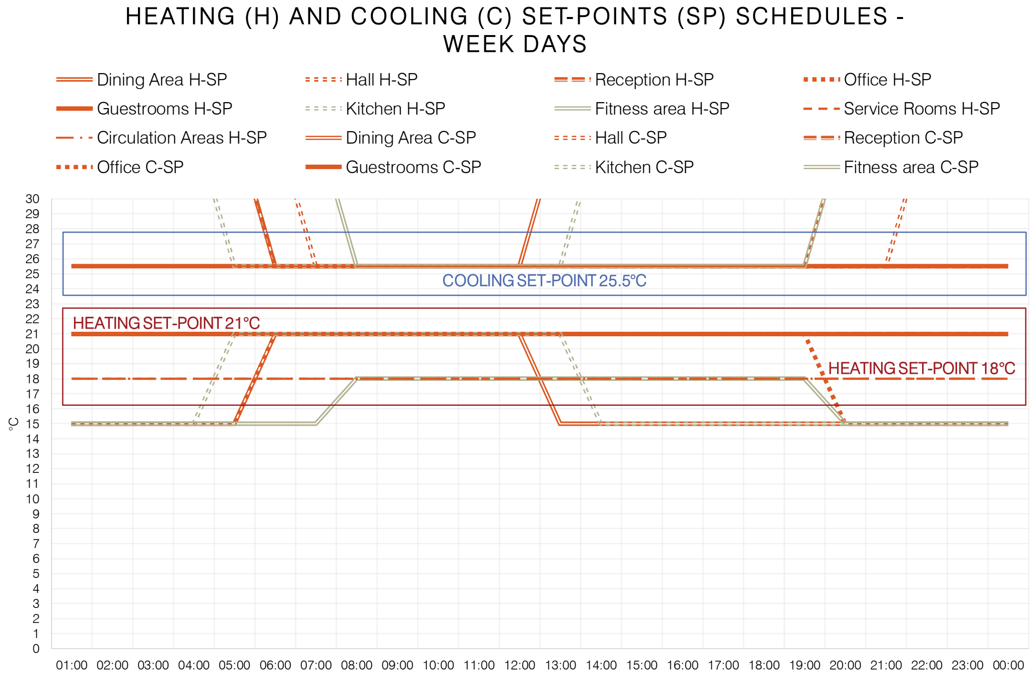


Figure 4-7: Weekdays heating and cooling operative temperature set-points schedules. Weekend schedules have very similar patterns

4.3.3 Energy use of the Reference Hotel

With the aim of assessing the baseline energy performance of the so-defined Reference Hotel, the model was built in Energy Plus (version 8.3) by implementing the detailed information previously gathered.

The main outputs of the dynamic simulation are recalled in Table 4-7. The delivered energy values (DE columns in table) where converted into primary energy (PE) by applying the Italian conversions factors given in (Ministero dello Sviluppo Economico 2015b): 2,42 for electricity and 1,05 for natural gas. The obtained primary energy values, graphically represented in Figure 4-8, highlight how relevant the energy uses related to extra functions are in the overall energy performance and the very different breakdown of end-uses between hosting and extra functions.

Table 4-7: Delivered (DE) and Primary Energy (PE) use of the Italian existing RH for its functions

	Function	**Whole hotel**		**Hosting functions**		**Fitness area**		**Kitchen**	
	Share of the whole PE use [%]	100		81		6		13	
	Energy	DE	PE	DE	PE	DE	PE	DE	PE
End - uses	**Light.**	45	110	35	84	86	208	16	40
	Equip.	31	76	16	38	44	107	427	1033
	Fans & pumps	8	20	6	15	6	15	36	87
	Cool.	20	48	16	38	18	44	29	70
	Heat. & DHW	77	81	54	57	50	53	452	475
	Tot.	182	335	126	232	205	427	960	1704

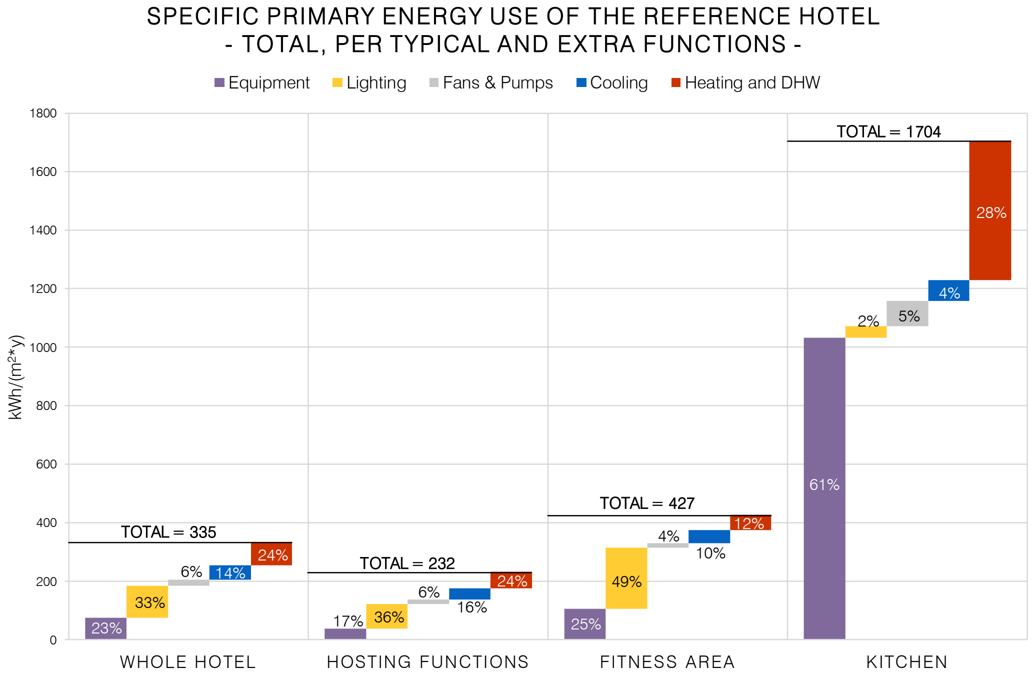


Figure 4-8: Primary energy per end-use of the entire hotel and for its typical and extra functions

4.3.4 NZEB requirements for an Italian Reference Hotel

Once the Reference Hotel is modeled as a representative building of the existing Italian accommodation sector, the precepts of inter-ministerial decree “Requisiti Minimi” enables the calculation of the minimum energy requirements to reach the Nearly Zero Energy level imposed at the Italian level.

The inter-ministerial decree “Requisiti Minimi”

The inter-ministerial decree (d.i.) “Requisiti Minimi” (Ministero dello Sviluppo Economico 2015b) came into force in October 2015 as the regulatory tool announced in Law 90/2013 (Presidente della Repubblica 2013), which, in turn, officially transposed the EPDB recast to the Italian context. The decree defines the requirements for nearly zero energy buildings and sets updated minimum energy standards, differentiated for new buildings and level of renovations and for target year. It replaced the Legislative Decree 192/2005 (Presidente della Repubblica 2005) and the Presidential Decree 59/2009 (Presidente della Repubblica 2009), introducing significant updates to the Italian building energy requirements.

In line with EU dispositions, the minimum energy performance requirements set in the d.i. refer to the typical energy use of the buildings, that shall reflect the annual global energy uses in primary energy for heating, cooling, ventilation, hot water production, and, in the non-residential sector, also for lighting, lift systems and escalators.

The main characterizing feature of the d.i. is the method proposed to verify the compliance with minimum energy requirements for new buildings and major renovations. Indeed, these minimum requirements are set based on the concept of *baseline building*. The *baseline building* is intended as a building that has the same geometry, orientation, geographic location, purpose of use and type of system than the building object of the evaluation, but that implements thermal and energy features (e.g. envelope U-values and plants efficiency) established by the Decree. The limit values for energy use for the building under evaluation, expressed in primary energy, are obtained through the calculation of the energy performance of the so-defined *baseline building*. The proposed evaluation approach is performance-based. Once the minimum energy requirements are set based on the baseline building, the real building is simply required to meet them through any suitable combination of design features. The conceptual shift from the prescriptive approach imposed by D.lgs.192/2005 is drastic: in the previous decree performance limit values were extrapolated as a function of degree days and the ratio building Surface/Volume and minimum envelope thermal performances had to be fulfilled. In the d.i., the prescriptive approach only persists for parameters mirroring the envelope thermal performance and in the case of minor renovations, where the installed building elements have to comply with minimum requirements. Additionally, minimum requirements are set for compliance with a calendar quota of energy produced from Renewable Energy Sources (RES). The legislative Decree 28/2011 (Presidente della Repubblica 2011) is mentioned in the d.i. as the reference regulation for deriving minimum and NZEB shares of RES. The calculation methodologies for the definition and verification of minimum requirements are based on an updated set of Italian technical standards: CTI 2014, UNI-TS Part 1, 2, 3 and 4 and UNI EN 15193. In these documents, guidelines for the calculation of thermal performances, climatization energy needs, of delivered and primary energy uses and of the RES share are provided.

Figure 4-9 schematically presents the categories of interventions, the related requirements, the approach adopted for their definition and the reference years for their validity as envisaged by the decree. In case of NZEBs, requirements in force for new constructions and major renovations mandatory from 2019/2021 apply.

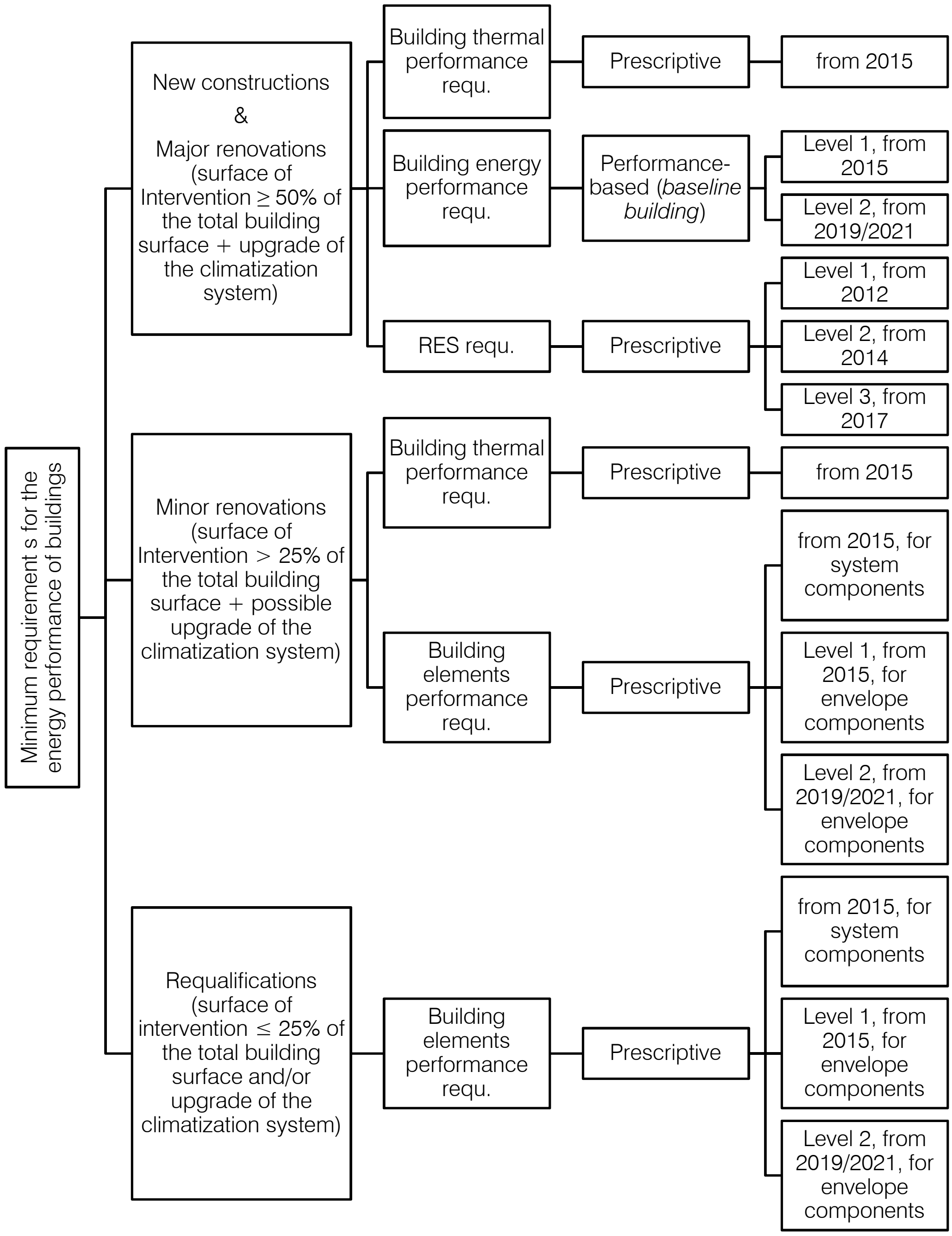


Figure 4-9: D.i. “Requisiti Minimi” schematic summary about the envisaged categories of interventions and the related types and levels of requirements

Nearly Zero Energy Level for the Reference Hotel

Based on the d.i. "Requisiti Minimi" dispositions, the Reference Hotel should simultaneously fulfil the following requirements, in order to reach the Nearly Zero Energy level.

Prescriptive requirements:

- The transmission heat transfer coefficient H'_T must be lower than a prescribed value. This requirement compulsorily applies for any new building and major renovation. As displayed in Table 4-8, the H'_T limit value is function of the Climatic zone and the Surface/Volume (S/V) ratio. The RH was hypothetically located in Turin, representative city of Climatic Zone E and has a S/V ratio of 0,28, therefore the H'_T limit value is 0,75.

Table 4-8: H'_T limit values for different climatic zones and S/V ratios

S/V	Climatic zone				
	A & B **HDD ≤900**	**C** **900<** **HDD ≤1400**	**D** **1400<** **HDD ≤2100**	**E** **2100<** **HDD ≤3000**	**F** **HDD >3000**
S/V≥0,7	0,58	0,55	0,53	0,50	0,48
0,7>S/V≥0,4	0,63	0,60	0,58	0,55	0,53
0,4>S/V	0,80	0,80	0,80	0,75	0,70

- The parameter $A_{sol,est}/A_{sup\ utile}$, representing the summer effective solar collecting area of glazed envelope elements normalized by the building net floor area, must be lower than 0,04 for non-residential building. Again, this limit value is valid for any new construction or major renovation, irrespective of the NZEB goal here set.

- System efficiencies η_H, η_W, η_C, referring to heating, hot water and cooling systems respectively, must be higher than the limit values for the *baseline building*, displayed in Table 4-10. This requirement is compulsory for any new building and major renovation.

- To reach the NZEB status, the calendar quota of renewable energy sources (RES) for domestic hot water (DHW) should exceed 50% of the energy demand

and, concurrently, the total calendar quota of RES to satisfy DHW+heating+cooling energy use must be higher than 50%.

Performance-based requirements:

- Indexes $EP_{H,nd}$ (heating energy need), $EP_{C,nd}$ (cooling energy need) and $EP_{gl,tot}$ (global total primary energy) must be lower than the corresponding performance indexes – $EP_{H,nd,limit}$, $EP_{C,nd,limit}$, $EP_{gl,tot,limit}$ – calculated for a the *baseline building* implementing reference features. These indexes are obtained by normalizing the energy needs and primary energy uses by the building heated net floor area. The primary energy considered in these calculations is the total one, which include the renewable and non-renewable share of primary energy of each energy carrier. The primary energy factors *f* that allow to derive primary energy – total, renewable and non-renewable – from delivered energy data, are given in the d.i.. The energy needs and performances limit values vary according to the target set for the building object in construction/renovation. As far as the NZEB target is concerned, limit reference values for the Reference Hotel were obtained as explained below.

***Baseline* NZEB RH**

The *baseline* NZEB RH has the same geometric and operational features of the RH, but it differs from it for envelope and system properties. Specifically, the *baseline* NZEB RH should present the envelope-related thermal properties shown in Table 4-9. Dealing with plants, the *baseline building* must implement the same systems as the building object of evaluation, but with predefined efficiencies. In the Reference Hotel, a centralized heating system using condensing boilers fueled by natural gas is installed for space heating and hot water production. It is a hydronic system with radiators as terminal units. A centralized hydronic cooling system with split is also installed. Based on these information, the corresponding *baseline building* system efficiency values are given in Table 4-10.

Table 4-9: *baseline building*'s envelope components' thermal properties

Envelope element	Thermal properties	Value
External walls	U-value	0,26 W/m^{2}K
Roofs	U-value	0,22 W/m^{2}K
Floors	U-value	0,26 W/m^{2}K
Glazings	U-value	1,40 W/m^{2}K
	g_{gl+sh}	0,35
Dividing walls between different units	U-value	0,80 W/m^{2}K

Table 4-10: *baseline building*'s plants and systems' efficiencies

System efficiency	Heating	Cooling	Hot water
Utilization sub-system efficiency η_u	0,81	0,81	0,70
Generation sub-system efficiency η_{gn}	0,95	2,50	0,85

The calculation of the reference heating ($EP_{H,nd,limit}$) and cooling energy need indexes ($EP_{C,nd,limit}$) was performed by replacing the reference input data referred to the envelope thermal properties (see Table 4-9) and artificial lights (see $EP_{L,tot,lim}$ below) in the Reference Hotel Energy Plus model, where a simulated IdealLoad plant system was implemented to allow the evaluation of the space heating and cooling needs.

The global total primary energy index $EP_{gl,tot,limit}$, instead, was obtained as:

$$EP_{gl,tot,limit} = EP_{H,tot,limit} + EP_{W,tot,limit} + EP_{V,tot,limit} + EP_{C,tot,limit} + EP_{L,tot,limit} + EP_{T,tot} \tag{4-1}$$

where,

- $EP_{H,tot,limit}$, $EP_{W,tot,limit}$ and $EP_{C,tot,limit}$ – the reference building total primary energy for heating, hot water and cooling indexes – were calculated following UNI-TS 11300-2 (CTI 2014b) dispositions;
- $EP_{V,tot,limit}$, primary energy index for ventilation, was set to 0, being the RH a naturally ventilated building;
- $EP_{L,tot,limit}$, primary energy index for lighting, was calculated based on UNI EN 15193 (CTI 2008) and UNI-TS 11300-2 (CTI 2014b), as required by the decree;
- $EP_{T,tot}$, primary energy index for lift systems, corresponds to same primary energy use of the elevator as simulated in the RH Energy Plus model.

Simulations and calculations results are reported in Table 4-11. These figures provide the overall picture of the minimum energy performance level that the Reference Hotel should meet to become a nearly Zero Energy Building.

Table 4-11: Performance indexes of the *baseline* NZEB RH

Index	Description	Limit value
$EP_{H,nd,limit}$	Heating energy need index	24,08 kWh/(m²·y)
$EP_{C,nd,limit}$	Cooling energy need index	27,51 kWh/(m²·y)
$EP_{H,tot,limit}$	Total primary energy for heating index	33,04 kWh/(m²·y)
$EP_{W,tot,limit}$	Total primary energy for hot water index	27,41 kWh/(m²·y)
$EP_{V,tot,limit}$	Total primary energy for ventilation index	0,00 kWh/(m²·y)
$EP_{C,tot,limit}$	Total primary energy for cooling index	50,80 kWh/(m²·y)
$EP_{L,tot,limit}$	Total primary energy for lighting index	62,83 kWh/(m²·y)
$EP_{T,tot,limit}$	Total primary energy for lift systems index	6,13 kWh/(m²·y)
$EP_{gl,tot,limit}$	Total global primary energy index	180,21 kWh/(m²·y)

Reference Hotel vs. *baseline* nearly Zero Energy Reference Hotel

The minimum performance levels imposed by Decree Requisiti Minimi require the performance data of the RH, briefly presented in sub-section 4.3.3, to be complemented and re-arranged, in order to define the RH as the starting point towards the fulfilment of the Italian NZEB requirements. To this purpose, figures for each requirement listed in the above section were calculated or derived from simulation results for the RH as well, as summarized below.

- The transmission heat transfer coefficient of the Reference Hotel, $H'_{T,RH}$, was calculated according to the Italian standard UNI/TS 11300-1 (CTI 2014a), as from the decree dispositions.

  Specifically, H'_T was calculated as:

$$H'_T = H_{tr,adj}/\sum_k A_k \quad [\mathrm{W/m^2K}] \tag{4-2}$$

  where,

  - A_k is the area of each envelope component, in m²;
  - $H_{tr,adj}$ is the overall transmission heat transfer coefficient, obtained as:

$$H_{tr,adj} = H_D + H_g + H_U + H_A \quad [\mathrm{W/K}]$$

(4-3)

where,

- H_D is the direct heat transfer coefficient by transmission to the external environment;
- H_g is the steady-state heat transfer coefficient by transmission to the ground;
- H_U is the heat transfer coefficient by transmission through unconditioned spaces;
- H_A is the heat transfer coefficient by transmission to adjacent buildings.

- To derive the parameter $A_{sol,est}/A_{sup\ utile}$ for the RH, the summer effective solar collecting area of glazed envelope elements ($A_{sol,est}$) was calculated as the sum of the sum of each glazed component $A_{sol,est}$, as shown in the formula below:

$$A_{sol,est} = \sum k \left(F_{sh,ob} \times g_{gl+sh} \times (1 - F_F) \times A_{w,p} \times F_{sol,est}\right) [\mathrm{m}^2]$$

(4-4)

where,

- $F_{sh,ob}$ is the shading reduction factor for external shadings, referred to July;
- g_{gl+sh} is the total solar energy transmittance of the of the transparent and shaded part of the element, referred to July;
- F_F is the frame area fraction, ratio of the projected frame area to the overall projected area of the glazed element;
- $A_{w,p}$ is the overall projected area of the glazed element;
- $F_{sol,est}$ is the correction factor for the incident solar radiation, calculated as the ratio between the average July solar radiation for the location and orientation object of analysis and the annual average solar radiation on the horizontal plane in Rome.

- Indexes $EP_{H,nd}$ and $EP_{C,nd}$ for the Reference Hotel were obtained by replacing in the RH Energy Plus model the actual plants with an IdealLoad plant system. Indeed, the heating and cooling outputs of the so-defined model represent the heating and cooling energy needs of the RH ($EP_{H,nd,RH}$, $EP_{C,nd,RH}$).

- The global total primary energy index, $EP_{gl,tot}$, does not take into account all energy uses, as equipment (except lift systems) is excluded for the energy performance calculation. Therefore, the results presented in Section 4.3.3 about the baseline energy uses of the RH were re-arranged in order to mirror the Decree requirements and assess the baseline energy consumption according to Italian law, in terms of EP_{gl}.

- System efficiencies for heating, hot water production and cooling were derived the information related to "System" sub-category, implemented in the simulation model.

- No renewable energy source is installed in the Reference Hotel, therefore the percentage of RES was set to 0% by default.

The obtained values for each requirement are presented in Table 4-12 in comparison with NZEB requirements.

Table 4-12: NZEB requirements for the RH vs. RH performances

Req.	**Description**	**Unit**	**NZEB values**	**RH values**
H'_T	Transmission heat transfer coefficient	W/m^2K	≤0,75	2,22
$A_{sol,est}/A_{sup\ utile}$	Normalized summer effective solar collecting area of glazed elements	-	≤0,04	0,03
$EP_{H,nd}$	Heating energy need index	$kWh/(m^2*y)$	≤ 24,08	69,32
$EP_{C,nd}$	Cooling energy need index	$kWh/(m^2*y)$	≤ 27,51	20,90
$EP_{gl,tot}$	Total global primary energy index	$kWh/(m^2*y)$	≤ 180,21	265,30
η_H	Heating plant and system efficiency	-	≥(0,81*0,95) 0,77	(0,81*0,97) 0,79
η_W	Hot water production plant and system efficiency	-	≥(0,70*0,85) 0,60	(0,70*0,97) 0.68
η_C	Cooling plant and system efficiency	-	≥(0,81*2,50) 2,03	(2,61*0,70) 1,83
RES_{DHW}	Share of renewable energy sources for DHW production	-	≥50%	0%
$RES_{DHW+H+C}$	Share of renewable energy sources for DHW, heating and cooling energy uses	-	≥50%	0%

4.3.5 Identification of Energy Efficiency Measures

The selection of Energy Efficiency Measures (EEMs) to be implemented in the Reference Hotel is the first step of the cost-optimal analysis, for the improvement of its thermal and energy performance in the challenge to reach the NZEB level. To this purpose, the RH was object of application of several retrofit measures, that could be broadly categorized in:

- Envelope Measures (E);
- Artificial Lighting Measures (L);
- System and Plants Measures (S);
- Renewable energy production measures (R).

Envelope Measures (E)

Due to the very poor RH thermal performances, retrofit measures took into account the overall improvement of the building envelope. In general, two levels of thermal performances were set as targets for each envelope element to be retrofitted. The targets were established based on the 2015 and the 2021 minimum requirements for envelope components for Reference Buildings modelled according to d.i. Requisiti Minimi. Coming to the retrofit approach, two different retrofit strategies were followed in parallel: the first foresees the use of standard materials and techniques to improve performances (e.g. EPS insulation and PVC windows), following a business-as-usual (BAU) renovation strategy; the latter uses eco-friendly materials, such as recycled wood-fiber insulating panels and windows with frames in local wood, to fulfil the same requirements. The implementation of this eco-strategy (ECO) seeks to comply with hotels green certifications requirements and will allow, in the followings of this thesis (Chapter 5), to investigate the effect of these measures on the overall financial performance of the RH, with respect to the corresponding standard measures. As a result, for each envelope component four stratigraphic combinations were defined, of which the detailed layers and properties can be found in Appendix C.

Dealing with the opaque envelope, the retrofit action was interpreted as a unique chance to renovate the overall image of the hotel. Therefore, an external insulation system was the selected action for the external opaque envelope, coupling improved thermal performance with a re-styling opportunity. Basement walls where insulated through insulating panels applied to the internal layer, while the ground floor was covered with a new floating floor, housing the insulation layer.

The building has an unheated roof, whose heat losses were reduced by insulating the semi-exposed ceiling of the hotel top-floor. The thermal performance requirements were met by implementing insulation layers with market available thickness, therefore the obtained U-values often outperform the two levels minimum requirements. U-values are reported in Table 4-13.

The substitution of all the glazed surfaces was the supposed retrofit option for the transparent envelope. Based on the thermal efficiency level to be reached, the single glazed windows were replaced by windows with low-emissivity argon filled double or triple pane glasses. Thermal properties are reported in Table 4-14.

Additionally, two different shading strategies were implemented on the RH. Their implementation was not compulsory, as the solar equivalent area of the Reference Building was already below the limit imposed by the decree Requisiti Minimi. Nonetheless, the well-known role of shadings in reducing summer overheating led he author to include these measures in the simulations tests. Particularly, the two investigated options are presented in Table 4-15.

Table 4-13: Opaque envelope's EEMs and related thermal performances

	RH	EEMs		Features			
				U-value [W/m²K]			
Opaque envelope	**U-value [W/m²K]**	**#**	**retrofit strat.**	**Lev. 1**	**Limit**	**Lev. 2**	**Limit**
External Wall	1,10	E1	BAU	0,28	0,30	0,24	0,26
			ECO	0,30		0,24	
External Wall 1	0,78		BAU	0,28	0,30	0,24	0,26
			ECO	0,28		0,24	
Basement Wall	0,69	E2	BAU	0,26	0,30	0,26	0,26
			ECO	0,27		0,24	
Basement Ground Floor	2,04		BAU	0,30	0,30	0,23	0,26
			ECO	0,28		0,25	
Semi-Exposed Ceiling	0,69	E3	BAU	0,23	0,25	0,22	0,22
			ECO	0,24		0,22	

Table 4-14: Glazed envelope's EEMs and related thermal performances

Glazed element	RH	EEMs		Features					
	U-value [W/m²K] (g_{gl} [-])	#	retrofit strat.	U-value [W/m²K] (g_{gl} [-])					
				Lev.1	Limit		Lev. 2	Limit	
Frame	-	E4	BAU	1,6	-		1,4	-	
			ECO	1,7			1,5		
Glass	-		BAU	1,3	-		0,8	-	
			ECO	1,3			0,8		
Whole Window	0,49/ 0,57 (0,85)		BAU	1,76 (0,49)	1,80		1,25 (0,49)	1,40	
			ECO	1,79 (0,49)			1,28 (0,49)		

Table 4-15: Shadings' EEMs

EEMs			Features
E5.1	Fixed Shadings		Fixed horizontal shadings above the south-oriented windows
E5.2	Automated Shadings		Exterior blinds installed on every windows, lowering when direct+diffuse solar radiation incident on the window exceeds 200 W/m²

Artificial Lighting Measures (L)

In the Reference Hotel model, primary energy use for lighting accounts for 33% of the total primary energy used by the whole hotel (see Figure 4-8). Additionally, artificial lights indirectly contribute to modify the heating and the cooling energy needs, by representing internal heat gains to be balanced by the building systems. Consequently, artificial lights-related EEMs have a crucial role towards the fulfilment of the NZEB requirements.

In the present application, the effect of the most basic retrofit intervention was tested: light bulbs substitution. The RH was assumed to have Compact Fluorescent Lamps (CFL) installed in the baseline model and two hypotheses of replacement were implemented. Option 1 (L1.1) foresaw the substitution of all CFLs with LED lights, by reducing the installed power of each zone by 60% based on ASHRAE directions (ASHRAE 2010). In option 2 (L1.2), the existing light-bulbs were substituted by LED lights only in common and working areas, where the lighting schedule is more predictable and the related energy uses are higher. Table 4-16 summarizes the features of the mentioned EEMs.

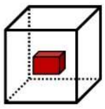
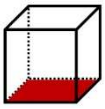
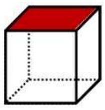
Table 4-16: Artificial lighting EEMs applied to each thermal zone of the RH

Features			**RH**	**EEMs** L1.1	L1.2	
LIGHTS TYPE			CFL	LED	CFL	LED
INSTALLED POWER	Fitness Area	W/m^2	14,74	5,90		5.90
	Toilettes		10	4		4
	Service Rooms		4,84	1,94	4,84	
	Dining Area		10	4		4
	Stairs& corridors		9,25	3,70		3.70
	Kitchen		10	4		4
	Offices		13	5,20		5.20
	Hall		10	4		4
	Reception		13	5,20		5.20
	Guest-rooms		10	4	10	
	TOTAL	kW	17,44	6,98	10,41	2.81
HOURS LIGHTS ON		h/year	7131	7131	3301	10960
LIGHT BULBS DURATION		h	10000	50000	10000	50000
LIGHT BULBS LIFESPAN		year	1.4	7	3	4,6

Systems and Plants (S)

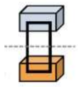
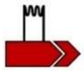
As mentioned above, the RH has hydronic centralized heating and cooling systems. The heating systems is fueled by two condensing boilers, respectively for space heating and domestic hot water, while the cooling plant is made up by an air-cooled chiller, connected to split units. The generation efficiency of these plants meets the Decree minimum requirements and therefore their substitution with new versions of the same plants was not included is the investigated EEMs. Conversely, the retrofit options envisioned the substitution of the HVAC system existing terminal units – radiators and cooling fan-coils – and the replacement of the heating and/or the cooling plant in order to test the impact of different energy carriers. Three options of terminal units replacement were tested, as displayed in Table 4-17.

Table 4-17: System-related EEMs

EEMs			**Features**	$\mathbf{T_{IN,Heating}}$ **[C°]**	$\mathbf{T_{IN,Cooling}}$ **[C°]**
S1.1	Four-pipes fan-coils		Four-pipes fan-coils as heating and cooling terminal units	50	7
S1.2	Radiant floor system		Radiant floor (RF) system for heating and cooling installed in guest-rooms and office spaces and four-pipes fan-coils (FC) in service areas. Two options of radiant floor system – BAU and ECO – were developed, detailed in Appendix A	45 (RF) 50 (FC)	16 (RF) 7 (FC)
S1.3	Radiant ceiling system		Radiant ceiling (RC) system for heating and cooling installed in guest-rooms and office spaces and four-pipes fan-coils (FC) in service areas. RC was coupled with de-humidifiers to avoid condensation	45 (RC) 50 (FC)	19 (RC) 7 (FC)

These low-temperature systems options, when connected to the existing plant, allow a better exploitation of the condensing boilers and chiller performances. Additionally, they open the doors to test low-temperature plants. Particularly, reversible heat pumps represent an interesting option, as they allow to gather all the heat and cold water production plants in a single unit, while exploiting renewable thermal energy. Among the available renewable thermal sources – water, ground, air – an air-to-water eat pump was chosen in this study, suitable for the installation in a dense urban context. A reversible air-to-water heat pump (S4.1), whose features are summarized in Table 4-18, replaced the condensing boilers and chiller in simulation models where low-temperature systems were installed. The second plant retrofit option (S4.2) entailed the connection of the building heating plant to the District Heating. Indeed, as the building was hypothetically located in Turin city center, the connection to the DH is a realistic option to be tested.

Table 4-18: Plant-related EEMs

EEMs			FEATURES	
S4.1	Air-to-water heat pump		Cooling capacity [kW]	114
			EER	2.61
			Heating capacity [kW]	136
			COP	3.23
S4.2	Connection to District Heating		Primary Energy conversion factor for DH of Turin	0.626

Renewable energy production measures

Two different renewable energy sources were tested on the RH: air and sun. Indeed, the air-to-air heat-pump, listed among the tested plants solutions, allows to exploit free thermal energy from outdoor air for hot and cold water production. On the other hand, solar energy is exploited for hot water production, with the installation of solar thermal flat plate collectors (ST), and for electricity generation, by installing mono-crystalline photovoltaic (PV) panels. Both types of solar panels were installed as integrated elements on the south-facing slope of the roof. In order to comply with NZEB requirements – simultaneous coverage of 50% of DHW and DHW+heating+cooling energy use – PV and ST panels were always coupled, covering the whole surface of the roof south-slope. Particularly, two configurations were tested for each solar system and combined.

Table 4-19 presents the main technical features and the two selected configurations for the solar thermal collectors (measure R1) and for the photovoltaic panels (measure R2).

Table 4-19: Renewable energy sources EEMs

EEMs		Features			
			Description	Config. 1	Config. 2
R1	 ST collectors	S_{coll}	Area of the ST collector	2,53 m^2	
		n_{coll}	Number of ST collectors in the	22	11
		$S_{ST,roof}$	Area of the ST system	55,66 m^2	27,83 m^2
R2	 PV panels	$P_{n,mod}$	Nominal power of the module	300 Wp	
		S_{mod}	Area of the module	1.65 m^2	
		η	Efficiency	0.184	
		n_{mod}	Number of modules in the system	84	56
		$S_{PV,roof}$	Area of the PV system	138,60m^2	92,40 m^2
		$P_{PV,roof}$	Nominal power installed	25,2 kWp	16,8 kWp

4.3.6 Identification of packages of Energy Efficiency Measures

Combinations of EEMs were created with the aim to meet the Italian legislation NZEB requirements. To this purpose, packages of EEMs were assembled in order to verify by subsequent steps the mentioned requirements, as summarized below.

STEP 1 - Creation of envelope-related packages of measures (PE), to verify compliance with envelope related NZEB requirements:

- Global heat transmission coefficient $H'_T \leq 0{,}75$ W/m^{2}K
- Normalized summer solar equivalent area of glazings $A_{sol,est}/A_{sup\ utile} \leq 0{,}04$

Business-as-usual (BAU) and Eco-friendly (ECO) retrofit approaches were investigated for the creation of these packages, listed in Table 4-20.

Table 4-20: Packages of envelope-related EEMs

BAU envelope-related packages		ECO envelope-related packages	
Code	**Description**	**Code**	**Description**
PE1	E1.1+E2.1+E3.1	$PE1_{eco}$	$E1.1_{eco}+E2.1_{eco}+E3.1_{eco}$
PE2	E1.2+E2.2+E3.2	$PE2_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}$
PE3	E4.1+E5.1	$PE3_{eco}$	$E4.1_{eco}+E5.1$
PE4	E4.2+E5.1	$PE4_{eco}$	$E4.2_{eco}+E5.1$
PE5	E1.1+E2.1+E3.1+E4.1	$PE5_{eco}$	$E1.1_{eco}+E2.1_{eco}+E3.1_{eco}+E4.1_{eco}$
PE6	E1.2+E2.2+E3.2+E4.2	$PE6_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}+E4.2_{eco}$
PE7	E1.1+E2.1+E3.1+E5.1	$PE7_{eco}$	$E1.1_{eco}+E2.1_{eco}+E3.1_{eco}+E5.1$
PE8	E1.2+E2.2+E3.2+E5.1	$PE8_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}+E5.1$
PE9	E1.1+E2.1+E3.1+E4.1+E5.1	$PE9_{eco}$	$E1.1_{eco}+E2.1_{eco}+E3.1_{eco}+E4.1_{eco}+E5.1$
PE10	E1.2+E2.2+E3.2+E4.2+E5.1	$PE10_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}+E4.2_{eco}+E5.1$
PE11	E1.1+E2.1+E3.1+E4.2	$PE11_{eco}$	$E1.1_{eco}+E2.1_{eco}+E3.1_{eco}+E4.2_{eco}$
PE12	E1.2+E2.2+E3.2+E4.1	$PE12_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}+E4.1_{eco}$
PE13	E1.1+E2.1+E3.1+E4.2+E5.1	$PE13_{eco}$	$E1.1_{eco}+E2.1_{eco}+E3.1_{eco}+E4.2_{eco}+E5.1$
PE14	E1.2+E2.2+E3.2+E4.1+E5.1	$PE14_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}+E4.1_{eco}+E5.1$
PE15	E1.2+E2.2+E3.2+E4.1+E5.2	$PE15_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}+E4.1_{eco}+E5.2$
PE16	E1.2+E2.2+E3.2+E4.2+E5.2	$PE16_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}+E4.2_{eco}+E5.2$
PE17	E1.1+E2.1+E3.1+E4.2+E5.2	$PE17_{eco}$	$E1.1_{eco}+E2.1_{eco}+E3.1_{eco}+E4.2_{eco}+E5.2$
PE18	E1.2+E2.2+E3.2+E4.1+E5.2	$PE18_{eco}$	$E1.2_{eco}+E2.2_{eco}+E3.2_{eco}+E4.1_{eco}+E5.2$

STEP 2 - Based on the results of a preliminary comparison between the energy needs and primary energy uses of BAU and ECO packages of envelope EEMs, from this step onwards the investigation was focused on the business-as-usual approach only. The BAU PEs meeting envelope requirements were the basis for the implementation of Artificial Lighting Measures (PEL). The heating and cooling energy needs of the models implementing PEs and PELs were simulated to verify the compliance with NZEB energy needs limit values:

- Heating energy need index $EP_{H,nd} \leq 24{,}08$ kWh/(m^2·y)
- Cooling energy need index $EP_{C,nd} \leq 27{,}51$ kWh/(m^2·y)

STEP 3 - The BAU package of envelope and lighting measures satisfying energy need requirements was the baseline model for the implementation of new systems, plants and renewable energy sources. For these retrofit options, the fulfilment of primary energy performance and renewable energy requirements were investigated to meet the NZEB limits:

- Total global primary energy index $EP_{gl,tot} \leq 162{,}05$ kWh/(m^2·y)

- Share of renewable energy sources for DHW production $RES_{DHW} \geq 50\%$
- Share of renewable energy sources for DHW, heating and cooling energy uses $RES_{DHW+H+C} \geq 50\%$

To sum it up, the creation process of packages of EEMs went along with the energy analysis toward the fulfilment of the NZEB level. Only packages meeting the envelope and energy needs performance requirements were further investigated in terms of primary energy performance and share of renewable energy. Figure 4-10 displays the Packages of EEMs creation process.

Due to the (expected) very similar energy performance of BAU and the corresponding ECO package of measures, the simulation-based energy analysis of models implementing lighting, systems and renewable EEMs was performed for the BAU approach only. However, the cost-optimal methodology included in the evaluation all the created models implementing Packages of EEMs, with no performance-based selection, and considered both the BAU and ECO approaches to retrofit. Indeed, despite entailing very similar energy performances, the two approaches may differ significantly in terms of financial costs and benefits.

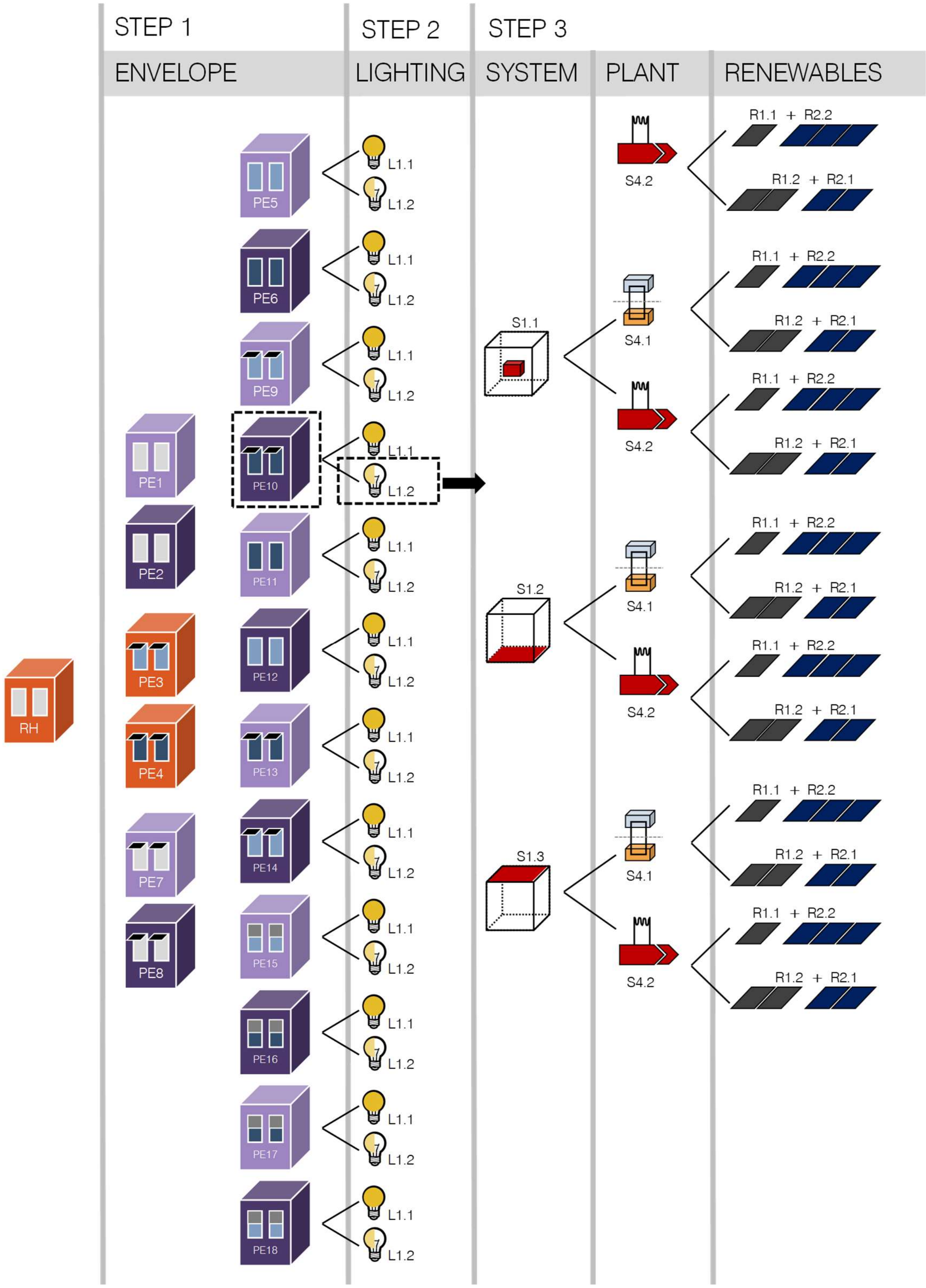


Figure 4-10: Creation process of Packages of EEMs

4.3.7 Energy analysis

As mentioned above, the energy analysis was carried out by subsequent steps. First, envelope performances were analyzed; then, climatization energy needs were evaluated for packages meeting the envelope requirements; lastly, primary energy and share of renewable were analyzed for packages of EEMs with suitable climatization energy needs. In the followings, energy performances calculation methodology and results are presented for each step.

Envelope thermal performances evaluation

For each envelope-related EEM and Package of EEMs implementing BAU and ECO retrofit approaches,

- the transmission heat transfer coefficient H'_T was calculated based on equation (4-2), i.e. following the calculation methodology provided n the Italian standard UNI-TS 11300-1 and referenced in Decree "Requisiti Minimi";
- the normalized summer effective solar collecting area of glazed elements $A_{sol,est}/A_{sup\ utile}$ met the mandatory minimum requirement in the RH original configuration already (see Table 4-12Table 4-12). As interventions on glazing and shadings can only further reduce this values, the $A_{sol,est}/A_{sup\ utile}$ of the retrofit options were not object of additional calculations and the requirements was assumed to be met by default.

Results are shown in Figure 4-11 for the BAU envelope retrofit options models and in Figure 4-12 for the ECO EEMs and Packages. In both figures, RH and NZEB reference building H'_T values are recalled and design solutions meeting the NZEB requirement framed by rectangles.

As expected, envelope thermal performances of corresponding business-as-usual and eco-friendly retrofit options were very similar. In both cases, calculation outcomes highlight that only with an overall renovation of the building envelope the Transmission Heat Transfer Coefficient requirement can be met. Indeed, only packages where thermal properties of both opaque and glazed components were upgraded have H'_T values lower than 0,75 W/m^{2}K. On the other hand, it must be noted that an intermediate level of insulation (i.e. the 2015 U-values for the reference building) is enough to satisfy this requirement, that in Italy compulsorily apply for any new building and major renovation.

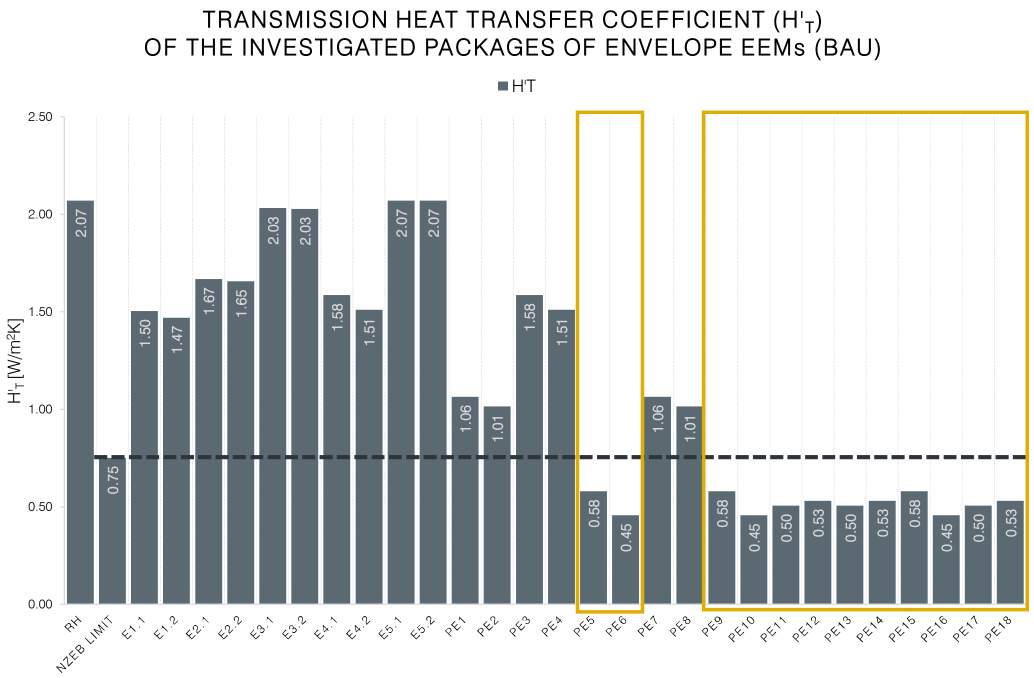


Figure 4-11: H'_T of models implementing envelope BAU EEMs and Packages, in comparison with the NZEB limit value

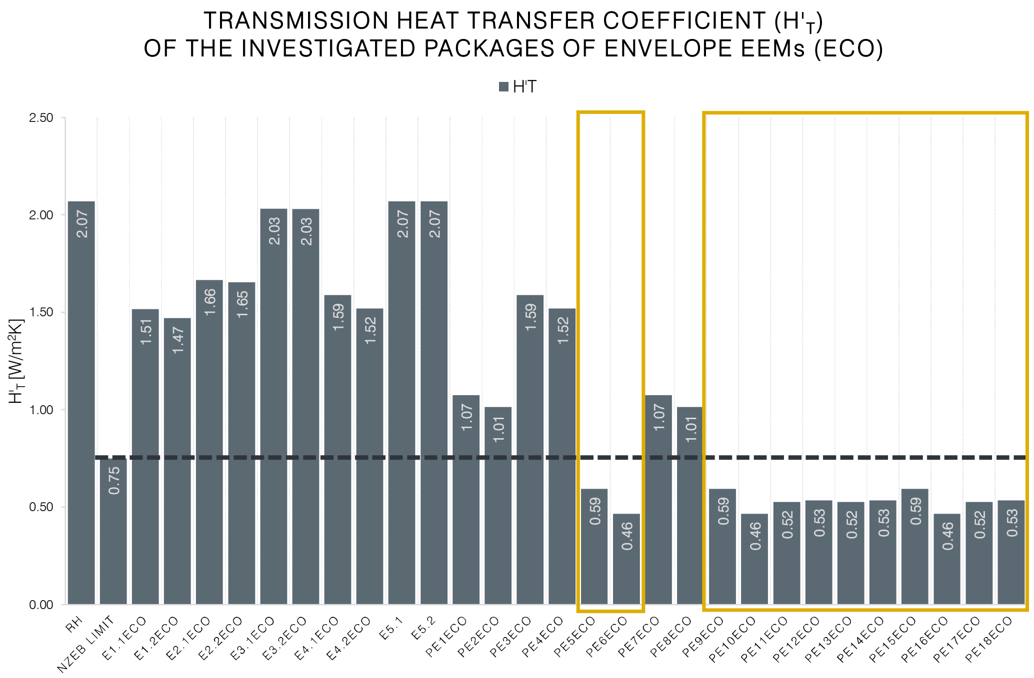


Figure 4-12: H'_T of models implementing envelope ECO EEMs and Packages, in comparison with the NZEB limit value

Heating and Cooling energy needs

Given the very similar thermal performance of BAU and ECO envelope retrofits options, the cooling and heating energy needs of the two series of simulation models showed the same patterns. Figure 4-13 displays the $EP_{H,nd}$ and $EP_{C,nd}$ indexes for the envelope-related retrofit options meeting the NZEB requirements.

These results led the authors to further investigate only BAU packages of EEMs, for the implementation of additional energy efficiency measures. Heating and cooling energy needs of the models implementing the selected envelope related packages of EEMs were obtained through dynamic energy simulation with Energy Plus. An IdealLoad System was modelled for all the retrofit options in order to derive the required outputs.

At this stage, Lighting retrofit measures (L1.1 and L1.2) were alternatively combined to the envelope packages of EEMs, in order to investigate the role that internal gains from artificial lights play in affecting the heating and cooling needs.

In Figure 4-14 the simulation-based results are reported. The histograms highlight the prominent role of artificial lighting internal gains in determining the cooling and heating energy needs. An overall advanced envelope upgrade, such as the one modelled for PE10, reduced by 73% the building heating need and increased by 78% the cooling energy need. All envelope-related packages were able to meet the $EP_{H,nd}$ limits but failed with the $EP_{C,nd}$. Light-bulbs substitution acted as a balancing measure toward the simultaneous fulfilment of both requirements. The replacement of all CFL light-bulbs with LEDs (L1.1) allowed to meet the cooling need limit value in all the models, but always led to heating needs above the imposed limit. Conversely, measure L1.2 – LEDs installation in common and working areas only – provided both $EP_{H,nd}$ and $EP_{C,nd}$ close to the limit requirements. Particularly, PE10L1.2 showed the best simulation results, with a $EP_{H,nd}$ 3% higher than the NZEB limit and $EP_{C,nd}$ 3% lower than the NZEB limit. Light adjustments to the envelope thermal properties or artificial lighting features would allow this package of EEMs to perfectly fit NZEB requirements. Therefore, PE10L1.2 was the selected model for the further step of the energy analysis, where the effect of systems, plants and RES was investigated in term of global primary energy.

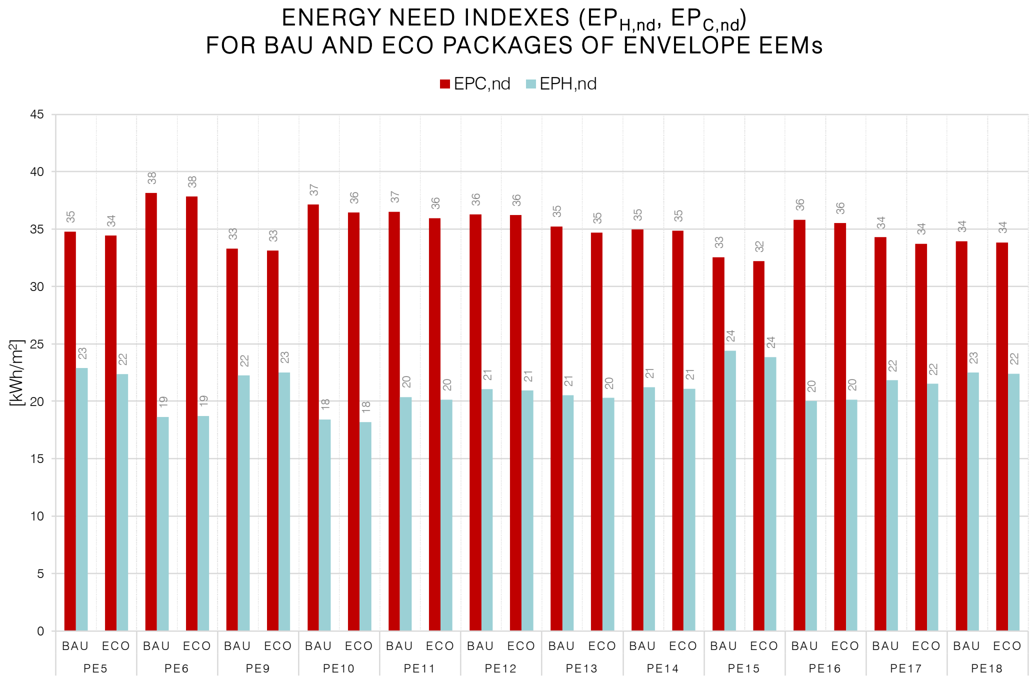


Figure 4-13: Heating and cooling energy need indexes ($EP_{H,nd}$, $EP_{C,nd}$) for envelope BAU an ECO Packages of EEMs complying with the H'_T requirement

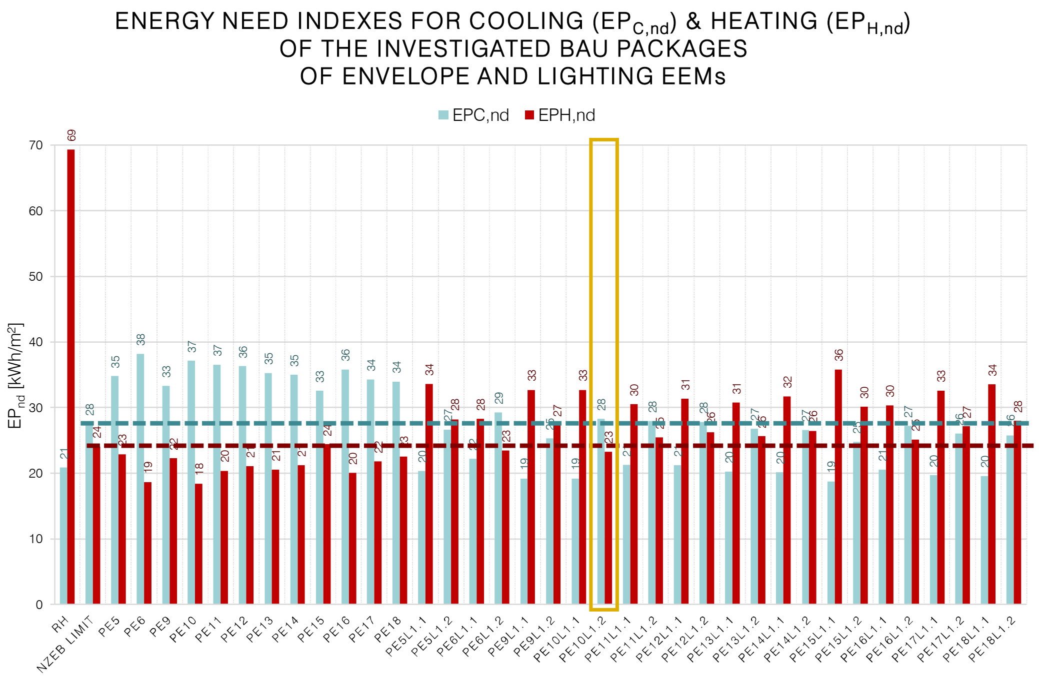


Figure 4-14: $EP_{H,nd}$, $EP_{C,nd}$ for envelope and envelope&lighting BAU Packages of EEMs, in comparison with the NZEB limit value

Global primary energy use

PE10L1.2 represents the baseline model for the implementation of different combinations of system, plant and RES retrofit measures in Energy Plus. These models were object of evaluation for their total and non-renewable global primary use. Simulation results, provided in terms of delivered energy, were translated into total (EP_{tot}) and non-renewable primary energy (EP_{nren}) by the application of the corresponding Italian conversion factors (respectively $f_{P,tot}$ and $f_{P,nren}$) given in Decree Requisiti Minimi and recalled in Table 4-21. The total global primary energy use was investigated first, as it allows direct comparison with the NZEB $EP_{gl,tot,limit}$.

Table 4-21: Primary energy conversion factors

Energy carrier	$f_{P,nren}$	$f_{P,tot}$
Natural gas	1,05	1,05
Grid Electricity	1,95	2,42
District Heating	0,626	0,626
Thermal energy from solar collectors	0	1
Electricity from photovoltaic panels, micro-hydro/-wind turbines	0	1
Thermal energy form outdoor air - heat pump	0	1

Figure 4-15 illustrates the $EP_{gl,tot}$ values of all the studied models, displaying the relevance of each end-use. It must be noted that, in line with the Italian national requirements, energy uses from equipment other than elevators were not included in the calculation of the global primary energy index. In Figure 4-16 the total global primary energy values per energy carrier are shown.

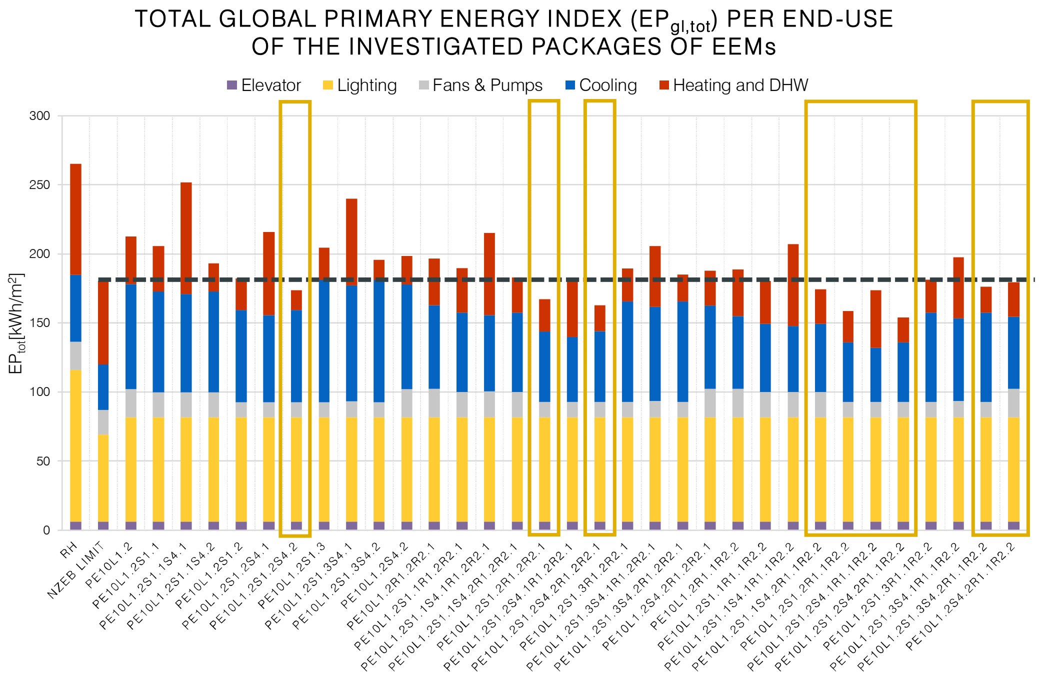


Figure 4-15: $EP_{gl,tot}$ per end-use for BAU packages of envelope, lights, systems, plants and RES EEMs, in comparison with the NZEB limit values

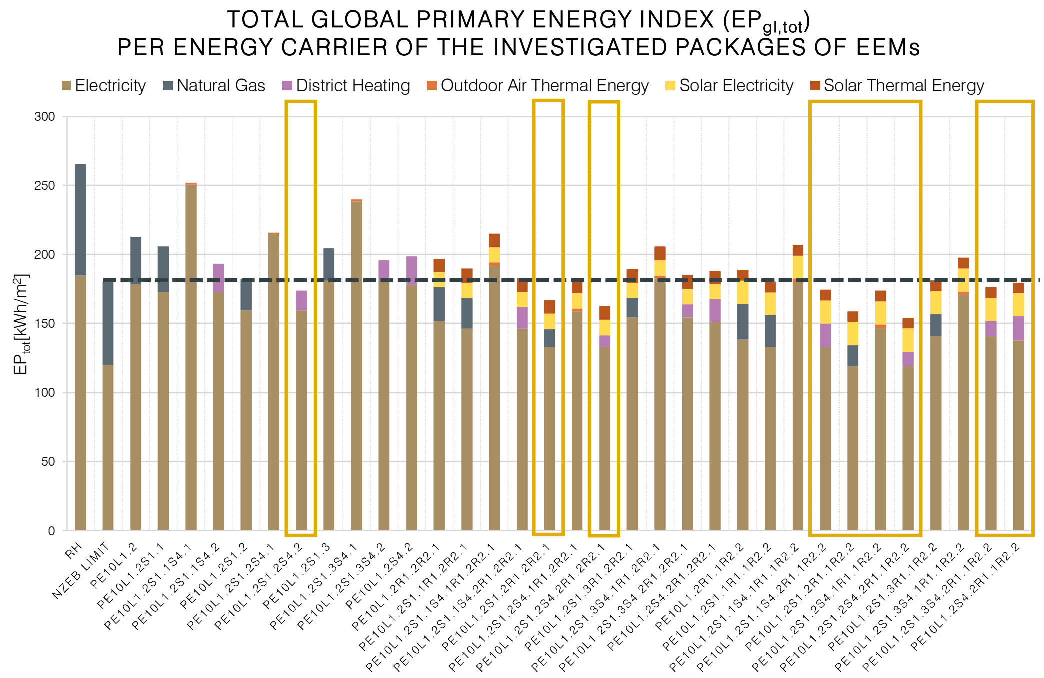


Figure 4-16: $EP_{gl,tot}$ per energy-carrier for BAU packages of envelope, lights, systems, plants and RES EEMs, in comparison with the NZEB limit values

Simulation results show that nine of the investigated combinations of EEMs were able to decrease the RH global primary energy need below the NZEB limit. Recurring measures in these packages were: connection to District Heating (S4.2), radiant floor system (S1.2) and installation of ST and PV panels (R1.1/2 and R2.1/2). Particularly, the combined substitution of terminal units and plants, coupled with the installation 86 photovoltaic panels and of 11 solar thermal collectors led to the lowest $EP_{gl,tot}$ value (PE10L1.2S1.2S4.2R1.1R2.2=154 kWh/m^2).

Retrofit options including air-to-water heat pumps showed poorer energy performances with respect to their counterpart models (i.e. models with the same systems and RES-related EEMs, but different plant configuration). Indeed, simulation results showed that in the selected model of heat pump the share of exploited outdoor energy thermal air was too low to supply to the RH heating and cooling needs, entailing supplementary electricity uses for climatization.

Non-renewable global primary energy use

Based on Italian legislation, while $EP_{gl,tot}$ is the primary energy index to evaluate the fulfilment of minimum energy performance requirements (and the potential fulfilment of NZEB requirements), $EP_{gl,nren}$ is the primary energy index used for categorization of buildings into classes of energy performance (Ministero dello Sviluppo Economico 2015a).

The energy class of the studied packages of envelope, lighting, systems and renewable sources EEMs was investigated by calculating their $EP_{gl,nren}$ and the energy classes limits, based upon the RH *baseline* building $EP_{gl,nren}$. Figure 4-17 shows the obtained results.

The histogram (Figure 4-17) confirms RES EEMs, such as the installation of PV and ST panels, are pivotal for high energy classes. All packages of EEMs implementing PVs and STs outperformed the RH in terms of $EP_{gl,nren}$ value. Seven of them led to an energy class upgrade, from A1 to A2 class. Once again, the recurring measures in the better performing retrofit options were radiant systems, district heating and use of RES. As expected, these packages correspond to the retrofit solutions with the lowest $EP_{gl,tot}$ values.

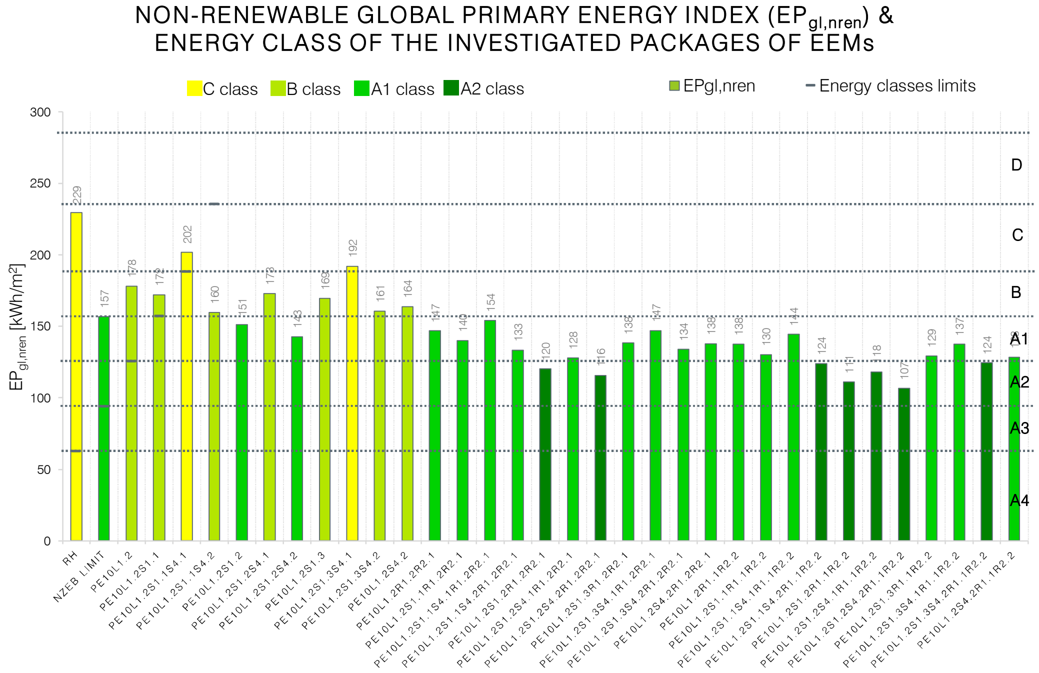


Figure 4-17: $EP_{gl,nren}$ for BAU packages of envelope, lights, systems, plants and RES EEMs, in comparison with the energy classes limit

Share of renewable energy

Fundamental requirement for a NZEB is that the "very low amount of energy required should be covered to a very significant extent by energy from renewable sources" (European Parliament 2010). In the Italian context, the "significant extent" of renewable energy asks NZEBs to simultaneously satisfy at least 50% of the energy need for DHW and 50% of energy needs for climatization and DHW.

To calculate this share, UNI-TS 11300-4 recommendations were followed. The energy uses of models implementing RES were compared to their counterparts, which provide the same amount of energy through the same plants and systems but without the auxiliary contribution of RES. The relative difference in energy use between the two models was the required share of RES.

Energy production from photovoltaic and solar thermal panels were direct outputs of the dynamic simulations. As far as heat pumps are concerned, the share of renewable thermal energy form outdoor air was obtained from dynamic energy simulation results as well, based EU guidelines (European Commission 2013).

Figure 4-18 displays the obtained results in comparison with NZEB and intermediate (2014) limits. This histogram clearly displays that all options of ST panels installations satisfied the minimum share of RES for DHW production, while the combined provision of solar thermal and photovoltaic panels (and heat pump, when present) was never enough to satisfy the building energy needs for climatization.

Reasons for the disappointing share of renewable energy sources, most often even below the 2014 limit value, may be found in the high electricity energy use for climatization purposes (fans and pumps, cooling and heating in case of heat-pump installation), that PV panels on roof south slope cannot compensate. Additional PV panels with favorable orientation should be installed to meet the NZEB target.

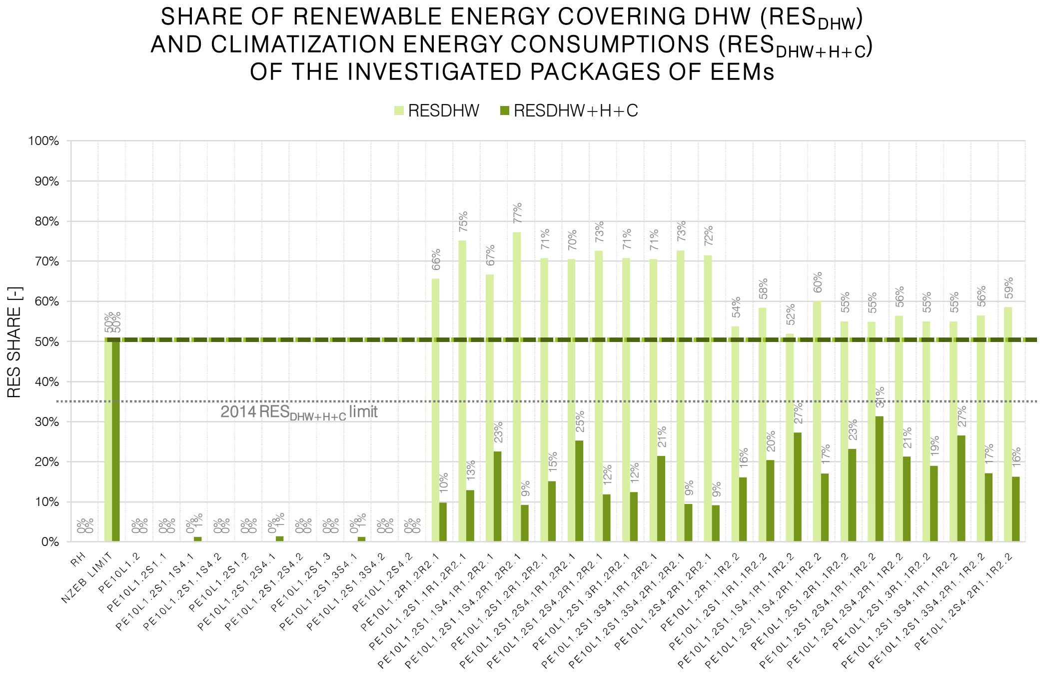


Figure 4-18: RES share of packages of envelope, lights, systems, plants and RES EEMs, in comparison with the NZEB and 2016 limit values.

4.3.8 Financial analysis of the packages of EEMs

The economic convenience of the considered retrofit options was investigated through global cost (C_G) from the microeconomic (financial) perspective, i.e. from investors' perspective. This approach provides a view on energy measures that are not cost-effective yet and it allows a realistic depiction the existing gap between the prescribed NZEB energy performance requirements and the cost-optimal level of energy performance.

As prescribed at the EU level, financial analysis “takes into account prices as paid by the end-consumer, including taxes and if applicable, subsidies” (European Commission 2012b). Therefore, Italian energy taxes and VAT were included in the costs calculation. On the other hand, subsidies were not considered at this stage of the analysis, as their amount may vary from year to year. In Chapter 5 the effect of subsidies as financial benefits will be tested on selected packages of EEMs.

Recalling EN15459 definition, the global cost of each retrofit option is the sum of the present values of costs incurred during a defined calculation period, taking into account the residual values of installations with longer lifetime (CEN 2007c). As the counterpart of residual values, four main cost categories are included in the global cost:

- Initial investment costs (C_I), that include all costs all the cost incurring up to the point when the renovated components of the building are delivered to the owner;
- Annual costs (C_a), that cover:
    - Running costs (C_r), which take into account annual maintenance costs (C_m), operational costs (C_o), energy costs (C_e) and added costs (C_{ad}),
    - Replacement costs (V_n), based on the lifetime of the components installed in the buildings and that may need to be replaced,
- Disposal costs (C_d), if applicable, include the costs for destruction, removal, transport and recycling of building elements.

The calculation period (τ) for these costs typically refer to the expected economic lifetime of the building, i.e. to the average period that occurs between two sets of renovation actions. Following Regulation N° 244/2012 suggestions, that consider 20 years as expected economic lifetime of commercial buildings, 20 years was the selected lifetime for the RH.

Present values of costs are referred to the starting year of the calculation period and rely on the discount rate (R_d) for their calculation. In accordance with the Guidelines accompanying Regulation N° 244/2012, net present values were calculated considering a real discount rate (R_R) of 4%.

R_R depends on national market interest rate (R) and inflation rate (R_i) as follows:

$$R_R = \frac{R - R_i}{1 + R_i}$$

(4-5)

Based on R_R, the discount rate R_d for a considered year p is calculated as:

$$R_d = \left(\frac{1}{1 - R_R}\right)^p$$

(4-6)

In the followings, an overview of the input data used to calculate each component of the global cost is provided.

Initial investment cost (C_I)

In this item, professional fees, taxes and construction costs are included.

- **Construction costs**. Being the RH hypothetically located in Turin, construction costs were derived from Piedmont Price List 2015 (Regione Piemonte 2014). As suggested by Guidelines accompanying Regulation N° 244/2012, costs related to building elements which do not have an influence on the energy performance of the building (e.g. wall painting) were not considered in the calculation. Additionally, costs that are the same for all measures/packages (e.g. cost of scaffolding) were not included. Detailed costs for each element included in any of the studied retrofit options are reported in Appendix D.
- **Taxes**. In order to consider Italian taxation in the investment costs, 22% VAT was applied to the construction costs.
- **Professional fees**. In Italy professional fees are regulated by D.M.143 31-10-2013, that prescribes the baseline payment for architecture and engineering design services in public tenders (Ministero della Giustizia 2013). This amount, expressed as a percentage of the project value, depends on the project costs and size, the category of building under consideration and the documentation to be produced. Due to the variable costs from one retrofit option to the other, an average percentage of 10% of the construction costs was here applied for the determination of professional fees.

Running Costs (C_r)

Added and operational costs other than energy were assumed to be constant for all the retrofit options and therefore were not considered in the global cost calculation. Conversely, maintenance and energy costs of the RH were included.

- **Maintenance costs (C_m).** The maintenance costs of the baseline RH were derived from the real building data, while their variation due to the effect of retrofit options was calculated as percentages of the related initial investment cost, based on the indicative data given in Annex A of EN15459.
- **Energy costs (C_e).** Energy prices, including energy taxes, were assumed constant during the calculation period. In order to realistically depict the energy tariff of a hotel building, the average electricity and natural gas tariffs of a medium size hotel building located in Turin were used as energy costs data. The average tariff VAT included, reported in Table 4-22, was calculated based on two years of energy bills records (from 2013 to 2015) of sample hotels located in Turin. Energy prices of District Heating refer to Turin[3] and they vary based on the end-use. For space heating, the average 2016 monomial tariff for commercial buildings with consumptions up to 350000 MCal/year (i.e. 407 kWh/year) was selected. For hot water production, a binomial tariff was the only option for commercial building, whose amount is split between fixed quota and consumption quota, both obtained as the 2016 average values. In order to derive energy costs, simulation based energy consumptions were coupled with tariffs for the considered energy carrier. As far as renewable energy is concerned, thermal and electric renewable energy was only considered as a way to reduce energy costs, therefore no financial income was included in terms of electricity sold to the grid.

[3] http://www.ilteleriscaldamento.eu/pdf/torino/torino_01_07_2016.pdf

Table 4-22: Energy tariffs of the considered energy carriers

	Energy tariff		VAT	Total Energy tariff
	Fixed Quota	Consumption quota		
Electricity	0.19 €/kWh		22%	0.231 €/kWh
Natural Gas	0.063 €/kWh		22%	0.077 €/kWh
District Heating for space heating		0.075 €/kWh	22%	0.092 €/kWh
District Heating for DHW production	0.231 €/m³heated	0.057 €/kWh	22%	1679 € + 0.071 €/kWh

Replacement costs (V_n)

Replacement costs are periodical costs whose occurrence depends on the lifespan of each component included in the retrofit options under consideration. Every time the component lifespan is shorter than the global cost calculation period (in this case, shorter than 20 years), replacements cost will enter in the global cost formula, in terms of their present value (i.e. replacement costs actualized based on the discount rate R_d). Lifespan of components and systems were assumed according to Annex A of EN 15459 and, when missing, from product specific fact-sheets.

Disposal costs (C_d)

As the building lifespan is longer than its estimated economic life-cycle, disposal costs were not included in the calculation.

Residual value ($V_{f,\tau}$)

The final value of any retrofit option is given by the sum of final values of all its components $V_{f,\tau}(j)$, which in turn are calculated based on their remaining lifetime, assuming a linear depreciation over its lifespan.

In mathematical terms, the residual value of each component or system is calculated as follows:

$$V_{f,\tau}(j) = V_0(j) \times (1 + R_p)^{n_\tau(j) * \tau_n(j)} \times \left(\frac{(n_\tau(j) + 1) \times \tau_n(j) - \tau}{\tau_n(j)} \right) \times \frac{1}{(1 + R_d)^\tau} \tag{4-7}$$

where,

- $\tau_n(j)$ is the lifespan of the considered component *j;*
- $V_0(j)\times(1+R_p)^{n_\tau(j)*\tau_n(j)}$ is the last replacement cost, when taking into account the rate of development of the price of products R_p;
- $n_\tau(j)$ is the total number of replacements during the calculation period;
- $\left(\frac{(n_\tau(j)+1)\times\tau_n(j)-\tau}{\tau_n(j)}\right)$ is the straight-line depreciation of the last replacement cost;
- $\frac{1}{(1+R_d)^\tau}$ is the discount rate at the end of the calculation period.

Global cost (C_G)

In mathematical terms, the sum of the present values of costs incurred during the calculation period is determined as follows:

$$C_G(\tau) = C_I + \sum_j\left(\sum_{i=1}^{\tau}\left(C_{a,i}(j)\times R_d(i)\right) - V_{f,\tau}(j)\right) \tag{4-8}$$

where,

- C_I is the initial investment cost;
- $C_{a,i}(j)$ is annual cost of year *i* for component *j*, including running costs C_r and replacement costs V_n;
- $R_d(i)$ is the discount rate for year *i*;
- $V_{f,\tau}(j)$ is the final value of component *j* at the end of the calculation period.

The present formula was applied for the calculation of global cost of all the investigated packages of EEMs, referring in parallel to the business-as-usual and the eco-friendly retrofit approaches.

Figure 4-19 and Figure 4-20 display the specific present values of the mentioned cost categories for the RH and all the created packages of measures, referring to the BAU and ECO approach respectively.

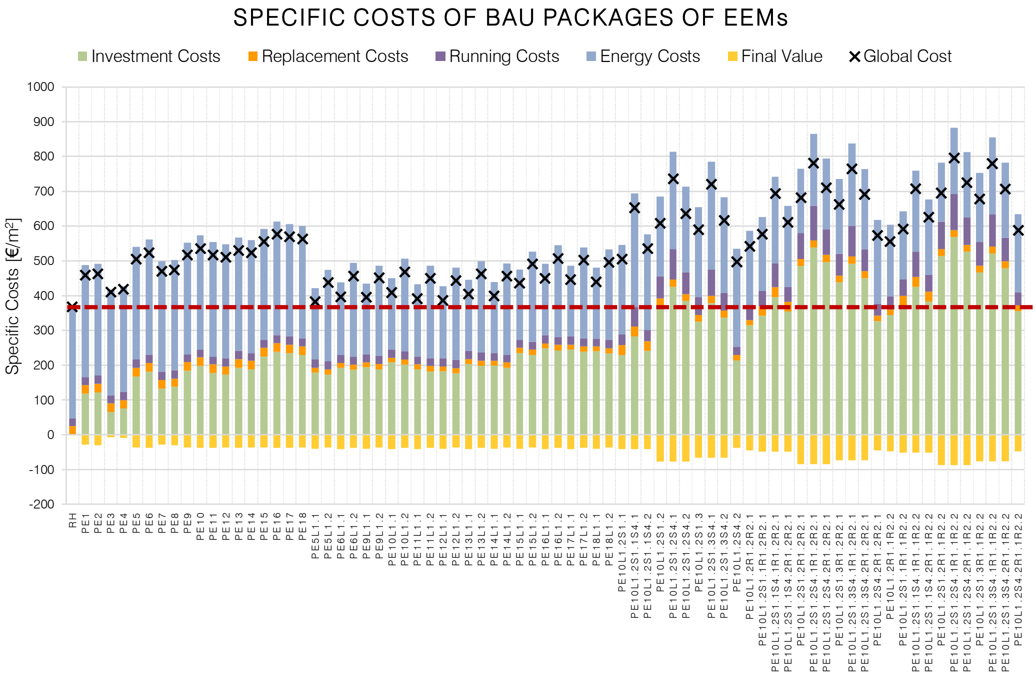


Figure 4-19: Specific present values of BAU packages of EEMs

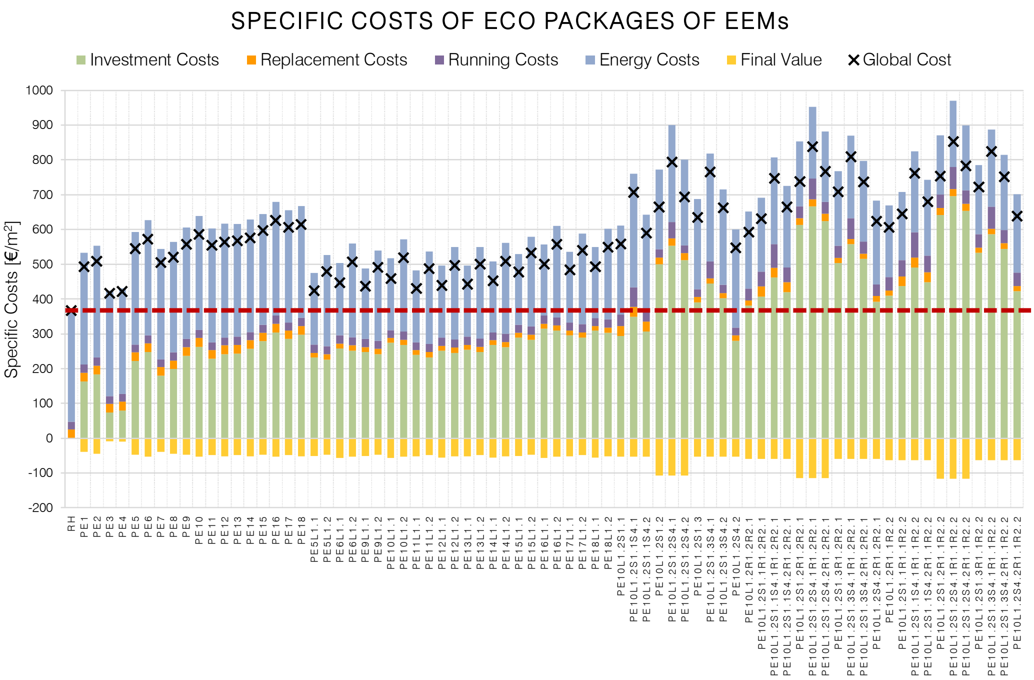


Figure 4-20: Specific present values of ECO packages of EEMs

The histograms highlight that none of the considered options was able to lower the global cost below the RH's one. In general, the missing balance between investment costs and energy costs reduction is the reason for these disappointing financial performances. Indeed, either the retrofit measures with lower investment costs were not able to significantly reduce the energy costs; or measures able to substantially reduce energy costs were too expensive. Despite still higher than RH C_G, retrofit options combining an overall envelope retrofit and total lights substitution with LEDs (PEnL1.1) were the most financially convenient.

As expected, applying an eco-friendly approach to retrofit entailed higher investment costs – +33% for envelope related EEMs – which caused a general increase the global cost of ECO packages of EEMs with respect to their BAU counterpart.

4.3.9 Derivation of cost-optimal levels

Exploring the cost-optimal level of energy performance requires the combined consideration of energy and financial performances of the RH and the investigated packages of measures. Indeed, "cost-optimal level means the energy performance level which leads to the lowest cost during the estimated economic lifecycle" (European Parliament 2010).

The energy performance is here reported in terms of total global primary energy index – $EP_{gl,tot}$– with the aim of evaluating the energy gap between the NZEB and the cost-optimal level of energy performance. The financial performance is represented by the global cost. To perform the analysis, the $EP_{gl,tot}$ of each modelled option was plotted versus the corresponding C_G in a scattered plot. $EP_{gl,tot}$ values are reported on the x-axis; C_G values on y-axis. From the so-created cloud of points it is possible to derive the cost-optimal curve by connecting points in the lower border of the cloud. The lower point of the cost-optimal curve represents the cost-optimal level of energy performance.

Figure 4-21 and Figure 4-22 display the cost-optimal graphs for BAU and ECO packages of EEMs respectively. As mentioned above, results deceptively show that the cost-optimum option is represented by the RH without retrofit. However, undertaking an overall envelope and artificial lighting upgrade can significantly decrease the primary energy use of the hotel with an irrelevant increase in Global cost. Particularly, considering the BAU approach (Figure 4-21), the cost-optimal curve almost flattens and creates a wide cost-optimal range, which includes the mentioned packages of lighting and envelope EEMs. Among them, package PE5L1.1 showed the best combination of energy and financial performance. In this retrofit option, envelope thermal properties were upgraded to meet the 2015 (intermediate) requirements and all CFL were substituted with LEDs. PE5L1.1 entailed a 4% increase in C_G, but a significant -36% in the $EP_{gl,tot}$ with respect to the RH. With the ECO approach, which uses more expensive construction materials to reach the same performance level, the C_G of PE5L1.1 was 15% higher than the RH (see Figure 4-22).

Unfortunately, the promising Primary Energy performances of PEXL1.1 packages do not allow to define them as NZEB retrofit options. Indeed, packages envisaging the overall substitution of artificial lights had too high heating energy needs, when compared to the NZEB limit (see Figure 4-14). For instance, the $EP_{H,nd}$ of Package PE5L1.1 exceeded by 40% the NZEB reference value.

Conversely, the top point of the cost-optimal curve – PE10L1.2S1.2S4.2R1.1R2.2 - met all the NZEB energy performance requirements (needs and primary energy), with a 42% $EP_{gl,tot}$ reduction. This retrofit option included an advanced upgrade of envelope thermal performances, the installation of fixed shadings, a radiant floor system in guest-rooms, the connection to district heating and the installation of 84 PV panels and 11 ST collectors. From the listed EEMs, it may be easily inferred why the low $EP_{gl,tot}$ is counterbalanced by a very high C_G: the global cost of this package of measures almost doubled (+97%) the RH C_G when considering the BAU approach and more than doubled (+110%) the RH C_G if the ECO-approach is considered. Beside this Package of EEMs, other retrofit options met both the NZEB energy needs and primary energy requirements, presenting slightly higher $EP_{gl,tot}$ and lower C_G. Among them packages PE10L1.1S4.2R1.1R2.2 showed the lowest global cost. It includes the same envelope, lighting, plants and renewables EEMs, but it does not foresee terminals substitution.

Based on these graphs, it is possible to quantify the performance and financial gap between cost-optimal and NZEB retrofit options for the RH. Referring to the business-as-usual measures, the cost-optimal level of energy performance can be identified in the EP_{gl} of PE5L1.1 (169 kWh/m^2), while the NZEB $EP_{gl,tot}$ is fixed at 180 kWh/m^2. Therefore, in terms of Primary Energy, cost-optimal and NZEB level do overlap. However, the energy needs of the cost-optimal package of EEMs does not comply with the NZEB requirements.

To evaluate the financial gap, the C_G of the cost-optimal package PE5L1.1 (382 €/m^2) was compared with the C_G of package satisfying all EP NZEB requirements with the lowest C_G (587 €/m^2), PE10L1.2S4.2R1.1R2. The important cost difference – 205 €/m^2 – stresses the existence of barriers towards the market up-take of NZEB renovations. Additionally, it must be noted that package PE10L1.2S4.2R1.1R2.2, here identified as representative of the cost of a NZEB renovation, in fact cannot be considered a NZEB renovation. Figure 4-18 shows that all retrofit options were not able to cover the NZEB minimum of renewable energy production devoted to climatization energy uses. To satisfy this requirement, additional PV or ST panels may be installed, entailing on the one hand decreased energy costs, on the other hand an increase in the initial investment costs. It is licit to infer that, in order to fully satisfy NZEB requirements, the financial gap will further widen.

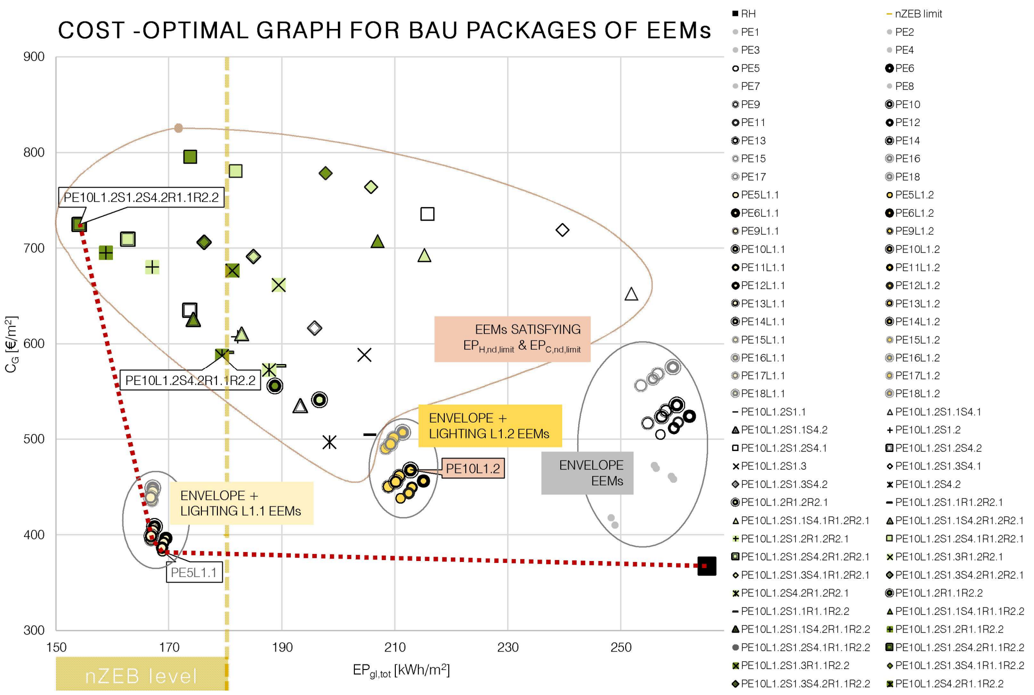


Figure 4-21: Cost-optimal graph referred to BAU packages of EEMs, in comparison with NZEB primary energy requirements

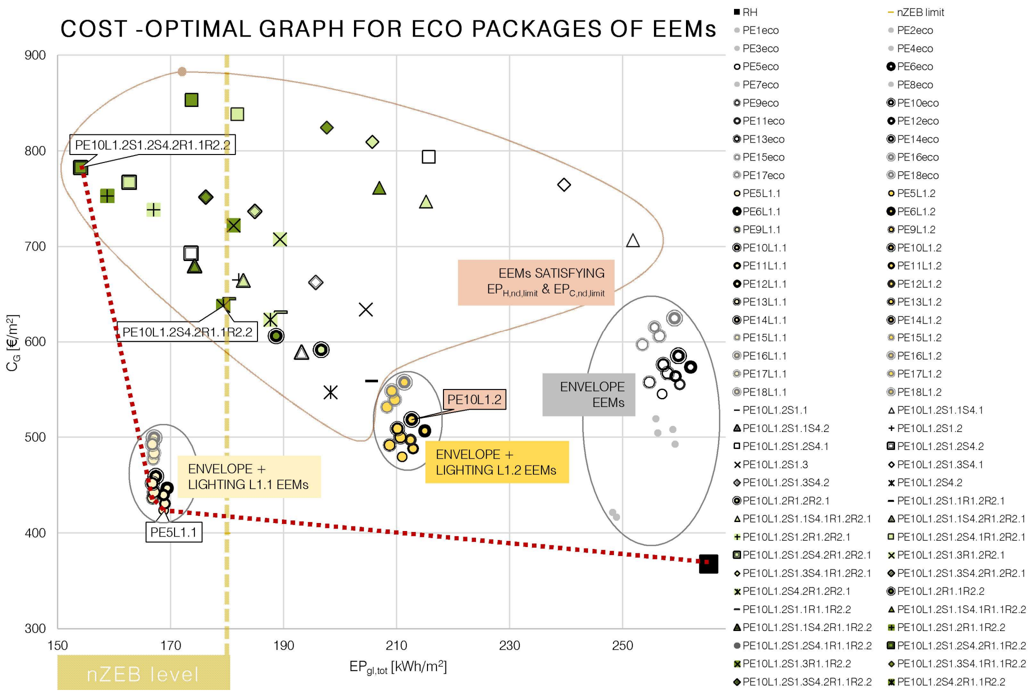


Figure 4-22: Cost-optimal graph referred to ECO packages of EEMs, in comparison with NZEB primary energy requirements

As a concluding remark, introductory to the investigations presented in the next section, the very different level of detail of input data for energy and financial calculations have to be highlighted. Energy performance results come from dynamic simulations, where very detailed information about the building envelope and systems were required. Conversely, the calculation of global cost is based on assumptions and simplified parameters aimed at providing a summary view of market conditions. In order to prove how much final results can change according to variations of these assumptions and parameters, a sensitivity analysis should be performed.

4.3.10 Sensitivity analysis

Sensitivity analysis is required by Regulation 244/2012 as a way to identify the most important parameters of a cost-optimal calculation. Particularly, the EU Commission asks to Member States to vary at least twice the discount rate for both the macro and micro-economic approach to the evaluation. Additionally, it is recommended to include price development scenarios for all the used energy carriers. In line with EU recommendations, in this section outcomes of the sensitivity analysis are presented. The evaluation took into account the influence on the global cost of BAU packages of measures of:

I. discount rate;
II. energy prices;
III. calculation period.

I. Discount rate

The baseline discount rate of 4% was varied to depict market conditions more realistically. From the theoretical point of view, a higher real discount rate is more appropriate for depicting a commercial, short-term approach to the valuation of investments. In practice, the current economic circumstances of the Italian market set the calculated real discount rate at values close to 0. Indeed, the Italian average market interest rate (R) for October 2015-October 2016 was around 0,02% (October 2016=0,00%) and the average inflation rate for the same period was around -0,12%[4]. Based on equation (4-5) , the Italian R_R is 0,14%.

Aimed at taking into account the two scenarios, in this sensitivity the R_R value was doubled (R_R = 8%) for simulating theoretical real market conditions and set to 0% to depict actual real market conditions in Italy. Generally speaking, the higher the discount rate, the lower the net present value of future costs. Conversely, the lower the discount rate, the higher the net present value of future costs.

Figure 4-23 and Figure 4-24 display the new cost-optimal graphs, with R_R equal to 8% and to 0% respectively. The grey dotted line stands for the original (R_R=4%) shape of the cost-optimal curve.

The hypothesis of an 8% real discount rate generally lowered the global cost of all packages of measures, but, by reducing the NPV of future costs, it further widened the financial gap between the cost-optimal solution – that in this scenario is the RH itself – and the best performing solutions, that is still identified in package PE10L1.2S1.2S4.2R1.1R2.2. From RH to PE10L1.2S1.2S4.2R1.1R2.2 the C_G increases by 155%. In the R_R=0% scenario, global costs of all packages of measures increased, but the relative difference between C_G decreased. In particular, the low R_R allowed to consider as cost-optimal all retrofit solutions envisaging the overall upgrade of envelope and artificial lighting.

[4] Data retrieved from: http://www.tradingeconomics.com/italy/indicators

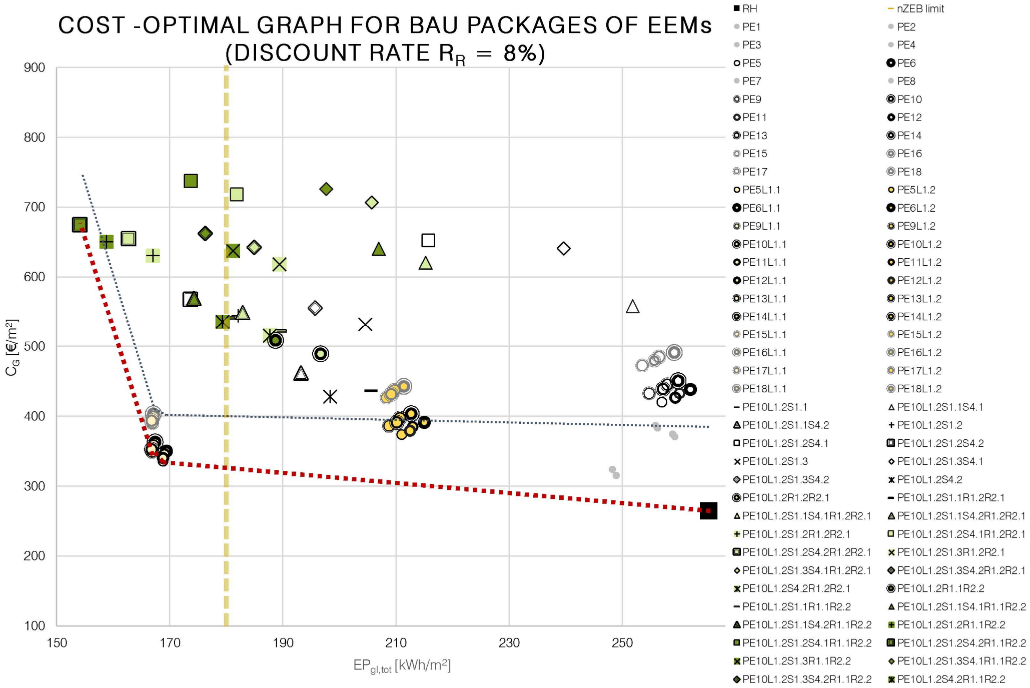


Figure 4-23: Cost-optimal graph referred to BAU packages of EEMs, using R_R=8%, in comparison with the original cost-optimal curve (grey dotted line)

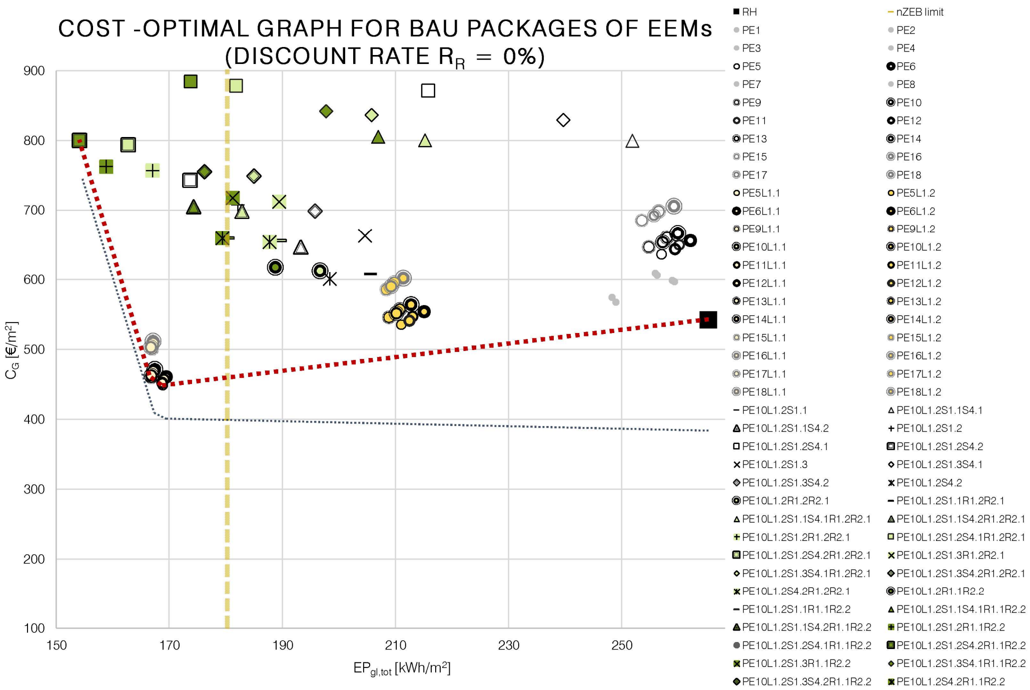


Figure 4-24: Cost-optimal graph referred to BAU packages of EEMs, using R_R=0%, in comparison with the original cost-optimal curve (grey dotted line)

II. Energy price

The hypothetical assumptions on energy price development were drafted with the purpose of depicting a pessimistic scenario in which the use of non-renewable energy sources is more and more penalized. In this view, based on the figures referred in guidelines, natural gas price was increased by 2,8% per year and electricity price by 2% per year. District Heating price was considered constant in view of depicting a worsening scenario. Indeed, from January 2013 to October 2016, the average yearly price of District Heating in Turin decreased by more than 20%[5].

Figure 4-25 depicts the C_G results plotted in the cost-optimal graph. In general, global costs increased with respect to the baseline scenario, but the relative difference between C_G of packages implementing RES and the RH decreased.

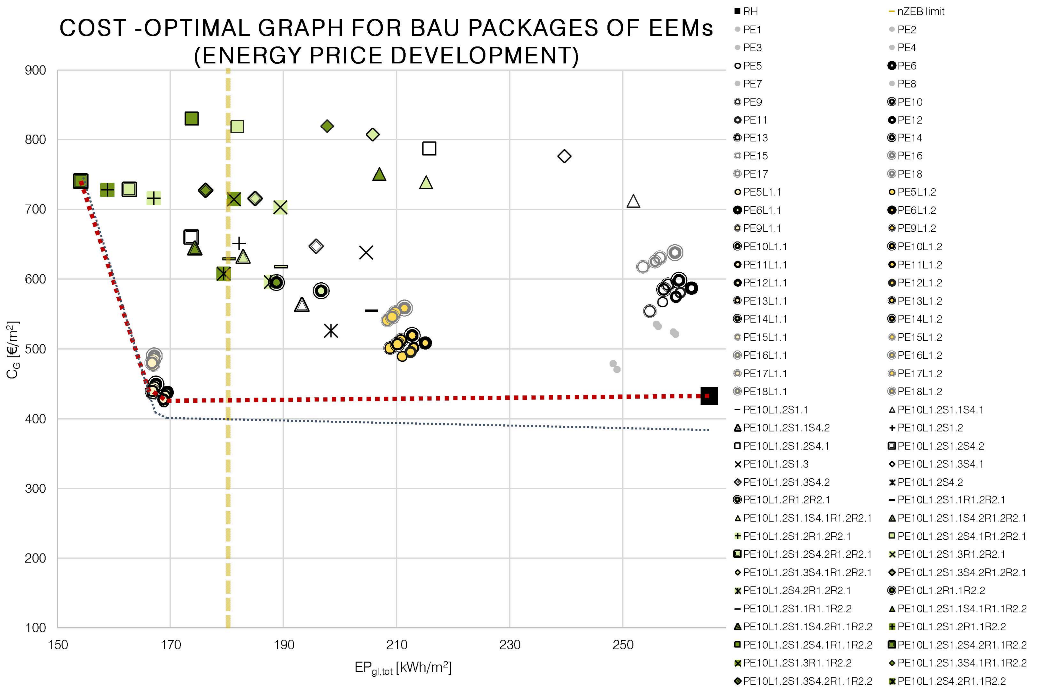


Figure 4-25: Cost-optimal graph referred to BAU packages of EEMs with the hypothesis of energy prices development, in comparison with the original cost-optimal (grey dotted line)

[5] Data retrieved from: http://www.ilteleriscaldamento.eu/pdf/torino/

III. Calculation period

Based on on-field interviews to hoteliers (see section 3.4.2), 20 years is a too long calculation period for evaluating the financial convenience of a retrofit intervention. In hotel businesses, the evaluative time horizon for such capital-intensive investments is usually lower than 6 years. Therefore, in the present investigation the calculation period was set to 5 years.

In Figure 4-26 the new cost-optimal graph is displayed. As expected, shortening the calculation period led to significantly lower global costs. However, the relative position of each package of EEMs in the cost-optimal graph did not vary and the relative differences in C_G further increased.

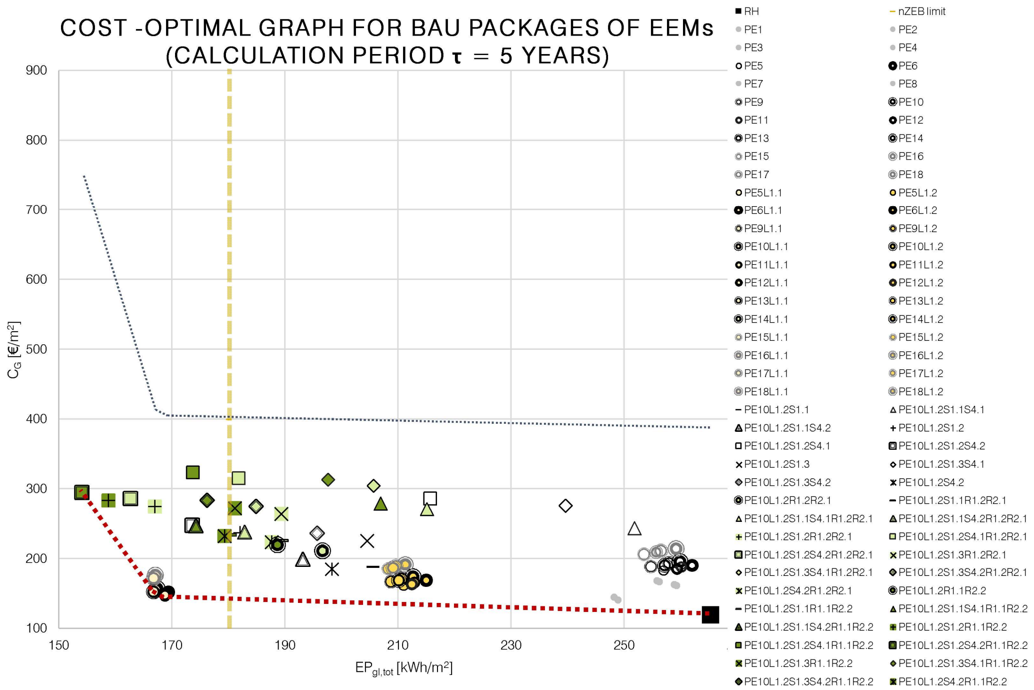


Figure 4-26: Cost-optimal graph referred to BAU packages of EEMs using a 5-years calculation period, in comparison with the original cost-optimal curve (grey dotted line)

4.3.11 Comfort-optimal analysis

Even if the traditional cost-optimal methodology does not call for comfort-related considerations, several studies in the recent years proposed to combine cost, energy and thermal comfort, when proposing optimal design solutions for buildings. Carlucci et al. (Carlucci et al. 2013), for instance, investigated through an optimization algorithm which combination of passive design solutions was able to guarantee a comfortable indoor environment and to minimize energy needs for space conditioning of a single-family net zero energy home located in the Mediterranean climate. On the same line, Ortiz et al. (Ortiz et al. 2016) proposed a method to develop cost-optimal studies for the energy renovation of residential buildings. This method considers thermal comfort, energy and economic criteria, in the sense that comfort was the main criteria for the selection of the energy efficiency measures to be implemented.

The analysis performed in the following paragraphs follows the same underlying principle of the referenced studies, aiming at verifying if the retrofit solutions proposed for the RH are able to improve the thermal comfort of its occupants. The specific target group for this investigation were hotels guests, that are assumed to be the most sensitive to comfort-related issues. Indeed, guests typically have high expectations about the quality of the hosting service offered by hotels (as they pay for it).

Thus, this piece of research aimed at investigating the thermal comfort conditions of a typical south-oriented guestroom during its occupied hours for all the analyzed simulation models. The imposed operative conditions were based on the I Comfort Category, therefore the study focused on verifying the frequency of occupied hours during which the PMV values lied in the (-0,2)/(+0.2) range (i.e. the I CC limits) during the annual simulations. Indeed, standard EN15251 standard (CEN 2007b) recommends PMV-PPD indexes (Fanger 1970) as the most suitable indicators of the thermal comfort level of a mechanically conditioned building and it suggests thermal performances to be evaluated by calculating the number of occupied hours (i.e. during which the building is occupied) when the comfort criteria are met.

Based on these recommendations, the hourly PMV values for a standard guestroom were retrieved from the dynamic simulations outputs and compared with the PMV comfort category limits. Additionally, these thermal comfort performance indicators were plotted versus the primary energy indexes in order to put in relation comfort and energy performances of the investigated retrofit options and to spot comfort-optimal solutions.

Figure 4-27 is a Tukey box-and-whisker plot depicting the statistical distribution of hourly PMV values throughout the year. In the graph, each box represents the PMV values distribution for a specific simulation model. Models implementing RES EEMs were omitted, since these measures do not influence the comfort level with respect to the corresponding models without RES. For every box in the graph, bottom and top indicate the minimum and maximum PMV values within which 50% of the hourly data is included. The upper and lower whiskers specify the PMV variability outside the upper and lower quartiles. The dotted horizontal lines represent the Comfort Category limits, as specified in EN15251. Using this type of graph, the most thermally comfortable solutions are represented by compact box-and-whisker elements (which stand for reduced PMV variations), with all values (i.e. the whiskers limits) comprised within the I Comfort Category PMV range.

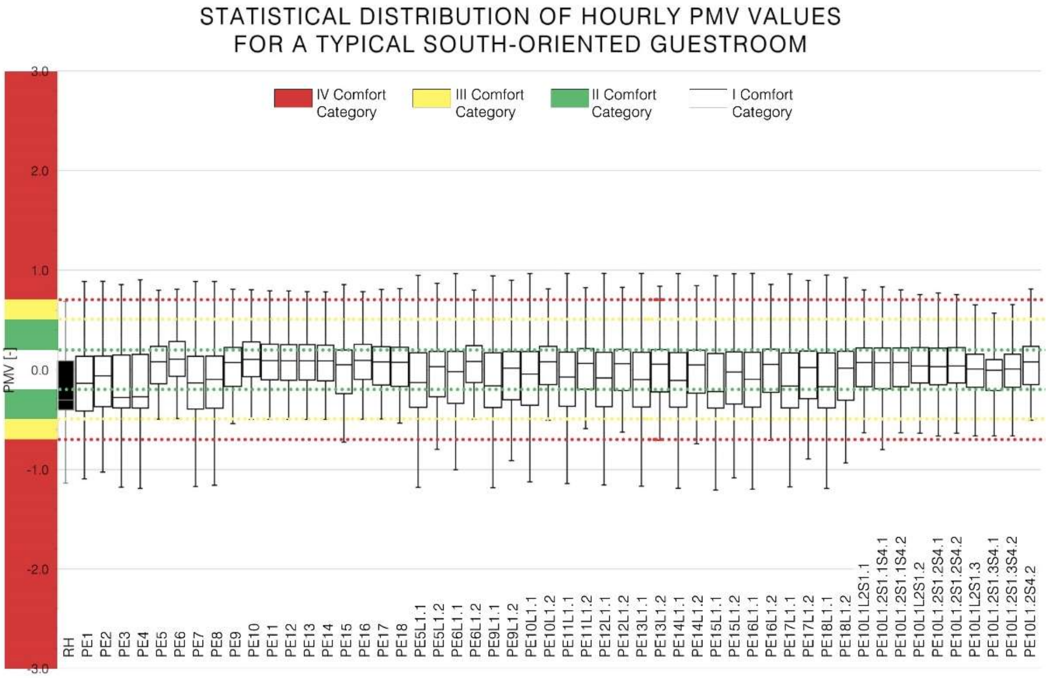


Figure 4-27: Statistical distribution of hourly PMV values in a typical RH guestroom in annual simulations of BAU packages of EEMs

Based on these considerations, results showed that:

- an overall thermal envelope retrofit (PE5, PE6, from PE9 to PE18) reduced the PMV variability with respect to the RH and shifted the PMV distribution to higher values (i.e. warmer thermal sensations);
- reducing artificial lighting internal gains in thermally efficient models caused an increase in PMV values variability, with values out of the acceptability range (i.e. in IV CC) both towards hot and cold thermal sensations. Packages

envisaging an overall lights replacement with LEDs showed the wider distributions;

- system-related measures were the only ones able to maintain I CC PMV values for 50% of the time (i.e. the corresponding boxes are placed between the I CC limits) and to keep acceptable PMV values for the whole year (i.e. the whiskers limits are placed below or nearby the III CC limits). Among these packages, radiant ceiling (measure S1.3) showed the best comfort performances.

In order to relate energy and thermal comfort performances, a comfort-optimal graph was built. Figure 4-28 depicts a scattered plot where $EP_{gl,tot}$ of each simulated package of EEMs is plotted versus the corresponding percentage of time during which PMV values lie within the I CC limits.

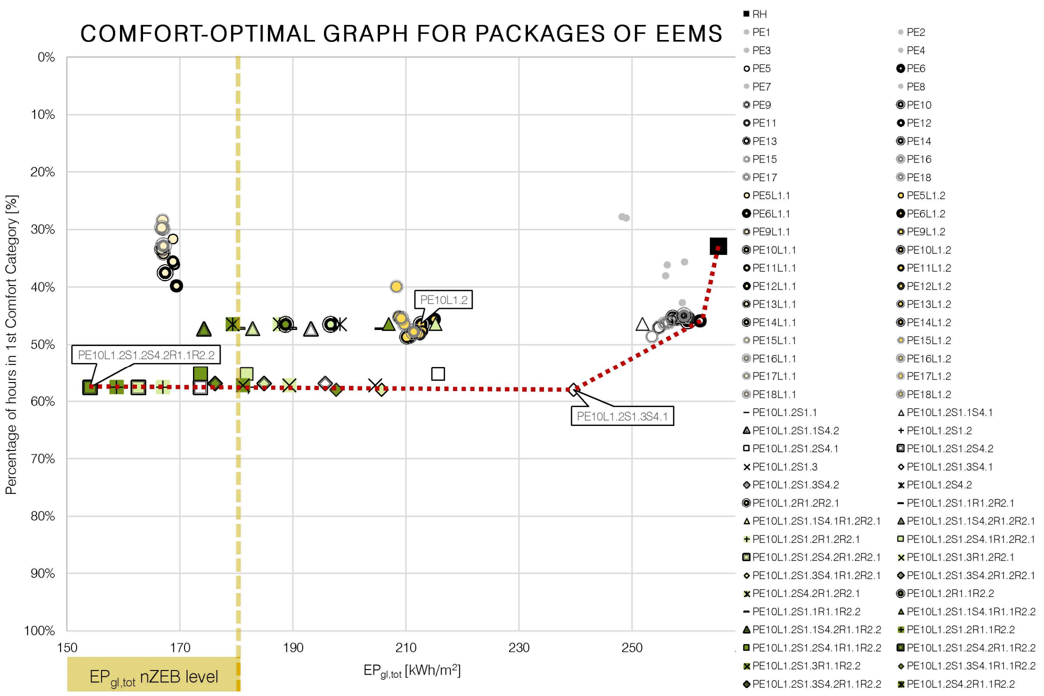


Figure 4-28: Comfort-optimal graph referred to BAU packages of EEMs, in comparison with NZEB primary energy requirements

The comfort-optimal curve (red dotted line in Figure 4-28) identifies the comfort-optimal retrofit options as the packages implementing radiant floors/ceilings. Since internal comfort conditions disregard the installation of RES, the range of primary energy values included in the comfort-optimal range is wide. Among them, the lowest value is represented by PE10l1.2S1.2S4.1R1.1R2.2, which was the higher point of the cost-optimal curve (see Figure 4-21). The comparison between Figure 4-21 and Figure 4-28 highlights that packages of EEMs complying with energy needs and primary energy NZEB requirements have contrasting economic and comfort performances. Packages with lower global costs (i.e. with better economic performance), such as PE10L1.2S4.2R1.1R2.2, have lower percentages of PMV values in the I Comfort Category (i.e. worst thermal comfort performance) and vice-versa. This combined analysis suggests that for a hotel building, where guests' comfort is a priority, financial convenience should not be considered as the only leading parameter to evaluate retrofit options.

4.4 Cost-optimal analysis for real hotels

Taking advange of the author's involvement in the neZEH project, detailed data of four Piedmontese hotels were exploited to test the potentialieties and limits of using a life-cycle-cost approach for cost-effectiveness analyses aimed at driving hoteliers towards the most suitable retrofit options. From the energy and economic analyses of these case studies derived three Master Theses, discussed at Politecinco di Torino and supervised by the author, and 2 scientific papers, papers VII and VII enclosed to this dissertation.

NeZEH project run for three years, from May 2013 to April 2016, and was co-financed by the Intelligent Energy - Europe (IEE) program. It involved 10 partners in 7 countries, including Italy, and aimed at accelerating the rate of refurbishment of existing buildings into NZEB supporting the hospitality sector and promoting the front runners. In particular, neZEH supported the NZEB goal within the Small-Medium Enterprises (SME) hotel sector. In line with the expectations, neZEH activities resulted in:

- 16 pilot projects in 7 countries (Croatia, Greece, France, Italy, Romania, Spain, Sweden),
- Practical training, informational materials and capacity building activities to support the implementation and uptake of neZEH projects
- An EU neZEH network and over 56000 hotel owners informed about the project
- A practical e-tool for hotel owners to assess their energy consumption state and to identify appropriate solutions for improving energy efficiency
- Marketing guidelines and promotional tools to assist front runners in communicating their environmental performance and improving their image

- EU and national position papers with recommendations for removing barriers and upscaling renovations towards NZE in the accommodation sector as a basis to fruitful debates in policy level also in the European Parliament.

The PhD candidate contributed to the project development for different aspects and actors. As a contributor to the technical expertise by the EU partner REHVA (Federation of European Heating, Ventilation and Air-conditioning Associations), support was provided for laying down the theoretical foundations of the nearly Zero Energy concept for hotel buildings, then fully developed within the PhD research activities. In collaboration with the Italian partner of the project, SiTI - Higher Institute on Territorial Systems for Innovation, the candidate was involved in most of the in-field activities related to the country-specific tasks, such as the Italian pilot project selection and analysis, trainings to professionals and hoteliers and the national position paper. It the framework of these activities at national level, it was possible for the author to get in touch with the applicants to the Italian neZEH call. Among them, four case studies were selected to be object of a parallel analysis with academic purposes, devoted to evaluate if the cost-optimal methodology is a valuable tool to drive private investment decisions on building retrofit.

With these premises, in these four applications to real hotel buildings, cost-optimal analysis was intended as a preliminary support tool to guide hoteliers' decisions. Given the case-specific features and needs of each hotel under investigation, the performed analyses focused on tailored proposals of Energy Efficiency Measures and exploited simplified tools. Quasi-steady energy simulation software were used, appropriate to provide first-stage information to investors, and financial evaluations made reference to simplified assumptions, aiming at providing qualitative rather than quantitative evidences.

In the followings, a collection of the analyzed case studies is presented in an organized form. For each hotel under investigation, dedicated paragraphs describe:

- Building features;
- Energy analysis assumptions;
- Financial analysis assumptions;
- Energy Efficiency Measures and packages;
- Cost optimal graph.

Aim of the so-structured sections is to give an insight of the most convenient retrofit strategies and levels of energy performance in existing hotels.

4.4.1 Case study 1

The full development of the analysis of Case study 1 was object of a Master Thesis discussed at Politecnico di Torino (Karagiannidou 2014) and supervised by the author.

Building features

Referring to the sub-categorization parameters and classes identified in section 4.3.1, Case study 1 is a large 4-stars hotel located the Middle Climatic zone, built between 1946 and 1960 and open all year. Table 4-23 presents the hotel's main features. In Table 4-24 and Table 4-25, instead, a concise description of the envelope and systems properties is provided.

Table 4-23: Case study 1's main records

Location	Turin (HDD = 2617)
Hotel type	Urban
Hotel Category	4*
Building typology	Multi-storey building
N° of floors	5 + basement and attic (5 conditioned floors)
Occupancy	Jan. – Mar.: 25-50%; Apr. – June: 50-75%; July – Sept.: 25-50%; Oct. – Dec.: 50-75%
N° of Staff members	30
Year of construction / refurbishment	1952 / 2006
Heated floor area	3780 m^2
Heated volume	13413 m^3
N° of guestrooms	106
N° of beds	200

Table 4-24: Case study 1's envelope thermal features

Envelope Element	Description	U-value [W/m^{2}K]
Roof	Pitched roof, with reinforced brick-concrete slab, low insulation	1,14
Internal floors	Ceiling with reinforced brick-concrete slab	1,30
External walls	brick masonry (60 cm)	1,02
Ground Floor Basement	Concrete floor on soil	2,00
External doors	Double-panel wooden door	1,70
Glazed external doors	Double-pane glass, aluminium frame	3,80
Windows	Double-plane glass, metal frame without thermal break	3,70

Table 4-25: Case study 1's system features

System	Features			
	Generation	Storage	Distribution	Emission
Heating system	Boiler fuelled by natural gas (installed after 1996)	How water storage tank	Centralized, vertical columns distribution	Radiators
DHW	Boiler fuelled by natural gas (installed after 1996)	How water storage tank for centralized DHW production	Centralized, with pipes partially outdoor	-
Mechanical ventilation	Installed in each guestroom			

Energy analysis assumptions

The energy performances under investigation are those prescribed by the Italian D.Lgs. 192/2005 (Presidente della Repubblica 2005), in force when the analysis of this case study was developed. The decree, valid until October 2015, transposed the EPBD (European Parliament 2002) to the Italian context and required to calculate the amount of primary energy necessary for maintaining the whole building at the standard comfort condition during the heating season (i.e. t_{indoor}=20°C). Building configurations were modeled in Docet energy simulation software[6]. The Docet version used was based on the Italian standard UNI/TS 11300 parts 1 and 2 (CTI 2014a; CTI 2014b) simplified calculation method. Developed

[6] http://www.docet.itc.cnr.it/

by the national research institutions ITC-CNR and ENEA, it was expressly intended to easily provide Primary Energy (EP_{gl}) values to be used in the Italian Energy Performance Certificates (EPCs). At the time of this research, the Italian EP_{gl} only took into account energy uses for heating and DHW, therefore Docet software only provided information about the delivered energy and primary energy used for these functions (electricity uses for lighting, appliances and cooling are not simulated).

Financial analysis assumptions

To have a preliminary evaluation of the financial convenience of any proposed intervention, the global cost formula items (see equation (4-8)) were defined as follow:

- C_I (investment cost) only included construction costs, which were derived from Piedmont Price List 2013 (Regione Piemonte 2012);
- C_m (maintenance costs) were calculated as percentages of the related initial investment cost, based on the indicative data given in Annex A of EN15459;
- C_e (energy costs) were assumed constant during the calculation period, equal to 0,087 €/kWh for natural gas[7] a to 0,178 €/kWh for electricity[8];
- C_o (other operational costs) and C_{ad} (added costs) were excluded from the calculation;
- V_n (replacement costs) were quantified based on construction costs given in Piedmont Price List 2013 and on the estimated lifespan of building components provided in Annex A of EN 15459;
- C_d (disposal costs) were not included in the calculation;
- R_R (real discount rate) was set to 4%, in line with the Guidelines accompanying Regulation N° 244/2012;
- τ (calculation period) was set to 20 years, following Regulation N° 244/2012 precepts.

Energy Efficiency Measures and packages

Based on the mentioned energy and financial calculation assumptions, the baseline EP_{gl} and C_G of Case study 1 were derived:

- EP_{gl}= 287 kWh/m^2·y

[7] Data source: www.centroconsumatori.it. Last access: January 2014.
[8] Data source: www.enelenergia.it/mercato/libero. Last access: January 2014.

– C_G = 715 €/m^2.

In order to test different strategies to drastically reduce the energy performance of the studied hotel, EEMs were proposed for reaching 2 different levels of performances. As far as envelope is concerned, level 1 refers to the minimum requirements in force until October 2015 (Presidente della giunta regionale del Piemonte 2007); level 2 (more demanding) refer to subsidized performance levels, promoted for the city of Turin until October 2015 (Città di Torino 2010).

In Table **4-26** EEMs simulated for Case study 1 are described and their impacts on the energy and financial performances are reported in terms of percentage variation with respect to the performance of the case study in its original configuration. EEMs showing at least a 20% energy reductions were selected for the derivation of cost-optimal levels. In Table 4-27 the resulting Packages of EEMs resulting selected for cost-optimal analysis are listed. Among them, only Packages showing at least 30% reductions were further analysed.

Table 4-26: Envisaged EEMs for Case study 1

EEM cat.	Element	Description	Code	EP_{gl}	Energy savings	C_G	C_I
				kWh/m²	%	€/m²	€/m²
Envelope	Ext. walls	Ext. insulation (U<0,33 W/m²K)	1a	241	16,03%	693	42
		Ext. insulation (U<0,25 W/m²K)	1b	155	45,99%	593	44
		Int. insulation (U<0,33 W/m²K)	2a	248	13,59%	248	33
		Int. insulation (U<0,25 W/m²K)	2b	245	14,63%	692	35
	Walls to non-heated areas	Curtain walling (U<0,80 W/m²K)	3a	283	1,39%	not calculated	
		Curtain walling (U<0,26 W/m²K)	3b	278	3,14%	not calculated	
	Roof	Top-surface insulation (U<0,33 W/m²K)	4a	262	8,71%	701	20
		Top-surface insulation (U<0,23 W/m²K)	4b	261	9,06%	701	21
	Floors to non-heated areas	Insulation (U<0,80 W/m²K)	5a	286	0,35%	not calculated	
		Insulation (U<0,26 W/m²K)	5b	284	1,05%	not calculated	
	Glazing	Triple pane glazing, PVC frame with thermal break (U_w<2,00 W/m²K)	6a	262	8,71%	728	55
		Triple pane glazing, PVC frame with thermal break (U_w<1,70 W/m²K)	6b	260	9,41%	727	57
Plants and systems	Heating system	Installation of radiant panels	7a	278	3,14%	922	141
		Installation of fan coils	7b	282	1,74%	738	14
		Insulation of distribution pipes	7c	280	2,44%	not calculated	

		Substitution of thermostatic valves	7d	282	1,74%	not calculated	
	Heating plant	Installation of condensing boilers	8a	217	24,39%	630	5
		Installation of air-to-water heat pump	8b	198	31,01%	557	22
	Ventilation	Installation of heat exchanger	9	245	14,63%	704	2
	Cooling system	Installation of split units	10	265	7,67%	734	16
Renewable energy sources	ST panels	ST panels exposed NE, 66 m^2, covering 63% of DHW energy need	11a	269	6,27%	655	17
	PV panels	PV panels exposed NE, 120 m^2 20 kWp	11b	258	10,10%	591	21

Table 4-27: Packages of EEMs created for Case study 1

Code	Included EEMs	Code	Included EEMs
P.Inv.2	1b + 4b	Pac1	1b + 4b + 8b
P.Inv.5	1b + 4b + 6a	Pac2	1b + 4b + 6a + 8a
P.Inv.6	1a + 4a + 6b	Pac3	1a + 4a + 6b + 8a
P.Inv.7	2a + 4a + 6a	Pac4	2a + 4a + 6a + 8b
P.Inv.8	2b + 4b + 6b	Pac5	2b + 4b + 6b + 7a + 8a
P.Imp.3	7b + 8b	Pac6	2b + 4b + 6b + 7b + 8b
P.Imp.5	7a + 8b	Pac7	1a + 4a + 6b + 7b + 8a
P.Imp.6	7b + 8a + 9	Pac8	1b + 4b + 6a + 7a + 8a
P.Imp.7	7b + 8a + 10	Pac9	1b + 4b + 6a + 9
P.Imp.8	7b + 8b + 10	Pac10	1b + 4b + 6a + 7b + 8a + 9
P.FR.1	11a + 11b	Pac11	1b + 4b + 6a + 7a + 8b + 11b
		Pac12	1a + 4a + 6b + 7b + 8a + 11a
		Pac13	8b + 11b
		Pac14	8b + 11a + 11b

Cost-optimal graph

Plotting primary energy versus global cost for the selected retrofit options allowed deriving preliminary information about the cost-optimal level of energy performances for Case study 1. The resulting graph is shown in Figure 4-29. Keeping in mind that the displayed primary energy performances refer to Heating and DHW-related energy uses, the cost-optimal level of energy performance lies in-between 140 and 190 kWh/m^2. These figures correspond to the lowest points of the cost-optimal graph, represented by packages 1 and 14. The first foresees a high level of envelope thermal performances and a heat-pump, the latter exploits renewables by installing solar and thermal panels to support a newly-installed heat-pump.

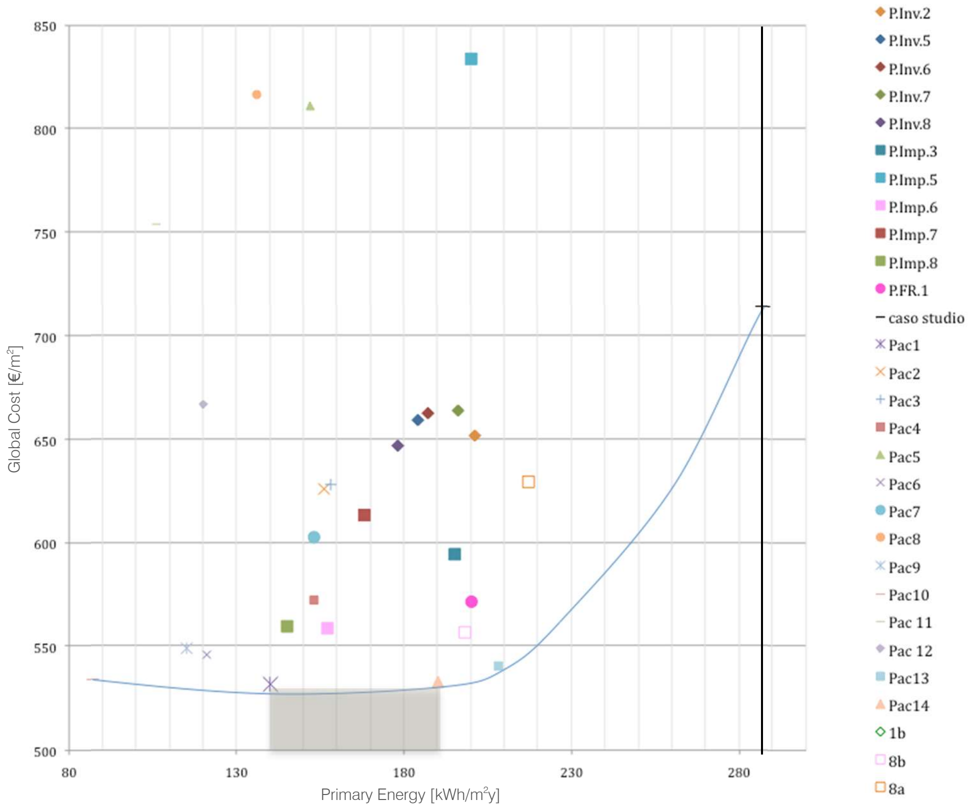


Figure 4-29: Cost-optimal graph for Case study 1. Source: (Karagiannidou 2014)

4.4.2 Case study 2

Case study 2 was also object of analysis of a Master Thesis discussed at Politecnico di Torino (Carbone 2014) and supervised by the PhD candidate. These analyses also resulted in a conference paper, enclosed in Part II of this dissertation as Paper VII.

Building features

Case study 2 is a large hotel located the mountains of Piedmont, built in 1929 as a sanatorium and converted into a hotel in the 80's, with middle and high school students as a favorite target. The main records are reported in Table 4-28. In Table 4-29 and Table 4-30, instead, concise descriptions of the envelope and systems properties are provided.

Table 4-28: Case study 2's main records

Location	Fenestrelle (HDD = 3781)
Hotel type	Mountain
Hotel Category	-
Building typology	Multi-storey building
N° of floors	5 + 2 basement levels
Occupancy	Opening period: approximately 10 months per year Jan. – Mar.: 25-50% ; Apr. – June: 50-75%; July – Sept.: 25-50% ; Oct. – Dec.: 50-80%
N° of Staff members	18
Year of construction / refurbishment	1930 / 1998
Heated floor area	5858 m^2
Heated volume	22669 m^3
N° of guestrooms	73
N° of beds	170

Table 4-29: Case study 2's envelope thermal features

Envelope Element	Description	U-value [W/m^{2}K]
Roof	Flat roof, with reinforced brick-concrete slab, low insulation	0,97
Floors to non-heated areas	Reinforced brick-concrete slab	1,12
External walls	Hollow-brick masonry (55 cm)	1,09
Walls to non-heated areas	Hollow-brick masonry (20 cm)	1,82
Ground Floor Basement	Concrete floor on ventilated cavity	1,50
Windows	Double window, each of them with single-plane glass and wooden frame	1,95

Table 4-30: Case study 2's system features

System	Features			
	Generation	Storage	Distribution	Emission
Heating system	3 boilers fuelled by natural gas (installed after 1996)	How water storage tank	Centralized, vertical columns distribution	Radiators
DHW	Boiler fuelled by natural gas (installed after 1996)	How water storage tank for centralized hot water production	Centralized, vertical columns distribution	-
Mechanical ventilation	Air Handling Units serving common areas in the basement			

Energy analysis assumptions

Again, the energy performances under investigation are those prescribed by the Italian D.Lgs. 192/2005, in force when the case study was analysed. Building configurations were modeled in Docet energy simulation software, to comply with the requirements mandatory at that time (referred to heating and DHW only). Therefore, the delivered energy and primary energy use data derived from simulations refer to these end-uses only.

Financial analysis assumptions

To have a preliminary evaluation of the financial convenience of any proposed intervention, the global cost formula items were defined as follow:

- C_I (investment cost) only included construction costs, which were derived from Piedmont Price List 2013 (Regione Piemonte 2012)
- C_m (maintenance costs) were calculated as percentages of the related initial investment cost, based on the indicative data given in Annex A of EN15459.
- C_e (energy costs) were assumed constant during the calculation period, equal to 0,091 €/kWh for natural gas a to 0,2 €/kWh for electricity. Tariffs were derived from the hotels bills;
- C_o (other operational costs) and C_{ad} (added costs) were excluded from the calculation.

- V_n (replacement costs) were quantified based on construction costs given in Piedmont Price List 2011 and on the estimated lifespan of building components provided in Annex A of EN 15459
- C_d (disposal costs) were not included in the calculation;
- R_R (real discount rate) was set to 4%, in line with the Guidelines accompanying Regulation N° 244/2012
- τ (calculation period) was set to 20 years, following Regulation N° 244/2012 precepts.

Energy Efficiency Measures and packages

The energy and financial calculations were first developed for the case study in its original configuration, resulting in:

- EP_{gl}= 320 kWh/m^2·y
- C_G = 563 €/m^2.

Technically feasible retrofit possibilities of the baseline model were defined in order to achieve energy savings through the improvement of the building envelope properties and of the building systems efficiency and through the exploitation of Renewable Energy Sources (RES).

Table 4-31 lists the single Energy Efficiency Measures and Table 4-32 presents the 13 resulting packages of measures.

Table 4-31: Envisaged EEMs for Case study 2

EEMs cat.	Description	U [W/m^{2}K]	Code
Envelope	External walls insulation (from internal side)	0,32	EEM1
	Walls to unheated insulation	0,32	EEM2
	Roof insulation (from internal side)	0,24	EEM3
	Windows substitution	0,90	EEM4
Plants	Substitution of gas boilers with condensing boilers		EEM5
	Substitution of heating terminals with radiant ceiling		EEM6
	Installation of mechanical ventilation system		EEM7
RES	Installation of Solar Thermal (ST) Panels (100% DHW need)		EEM8
	Installation of Solar Photovoltaic (PV) Panels (153 m^2, 19 kWp)		EEM9

Table 4-32: Packages of EEMs created for Case study 2

Code	Interventions
P1	EEM1 + EEM2 + EEM3 + EEM5
P2	EEM1 + EEM2 + EEM3 + EEM5 + EEM6
P3	EEM1 + EEM2 + EEM3 + EEM4
P4	EEM1 + EEM2 + EEM3 + EEM4 + EEM5
P5	EEM1 + EEM2 + EEM3 + EEM4 + EEM5 + EEM6
P6	EEM1 + EEM2 + EEM3 + EEM5 + EEM8
P7	EEM1 + EEM2 + EEM3 + EEM5 + EEM6 + EEM8
P8	EEM1 + EEM2 + EEM3 + EEM7 + EEM9
P9	EEM1 + EEM2 + EEM3 + EEM5 + EEM7 + EEM9
P10	EEM1 + EEM2 + EEM3 + EEM5 + EEM8 + EEM9
P11	EEM1 + EEM2 + EEM3 + EEM4 + EEM5 + EEM8
P12	EEM1 + EEM2 + EEM3 + EEM4 + EEM7
P13	EEM5 + EEM8

Cost-optimal graph

Results in Figure 4-30 highlight that the cost-optimal level of energy performance for Case study 2 is reached by 2 options, P1 and P6. The lowest global cost is obtained by P1 (235 €/m^2 and 103 kWh/m^{2}y), implementing to the baseline model opaque envelope thermal insulation and new condensing boilers. P6, where ST panels are added to the features of P1, provides better energy performance (82 kWh/m^{2}y) for a slightly higher global cost (242 €/m^2). The graph also provides a rationale for defining the best intervention to invest in. On one hand, packages with similar EP_{gl} may have different global cost (C_G), as exemplified for instance by EMM6 (EP_{gl} = 296 kWh/m^{2}y; C_G= 289 €/m^2) and EEM8 (EP_{gl}= 299 kWh/m^{2}y; C_G = 508 €/m^2). On the other hand, packages with very similar global cost can differ in energy performances. P5 (EP_{gl} = 94 kWh/m^{2}y; C_G = 300 €/m^2) and P13 (EP_{gl} = 195 kWh/m^{2}y; C_G = 297 €/m^2) are an example.

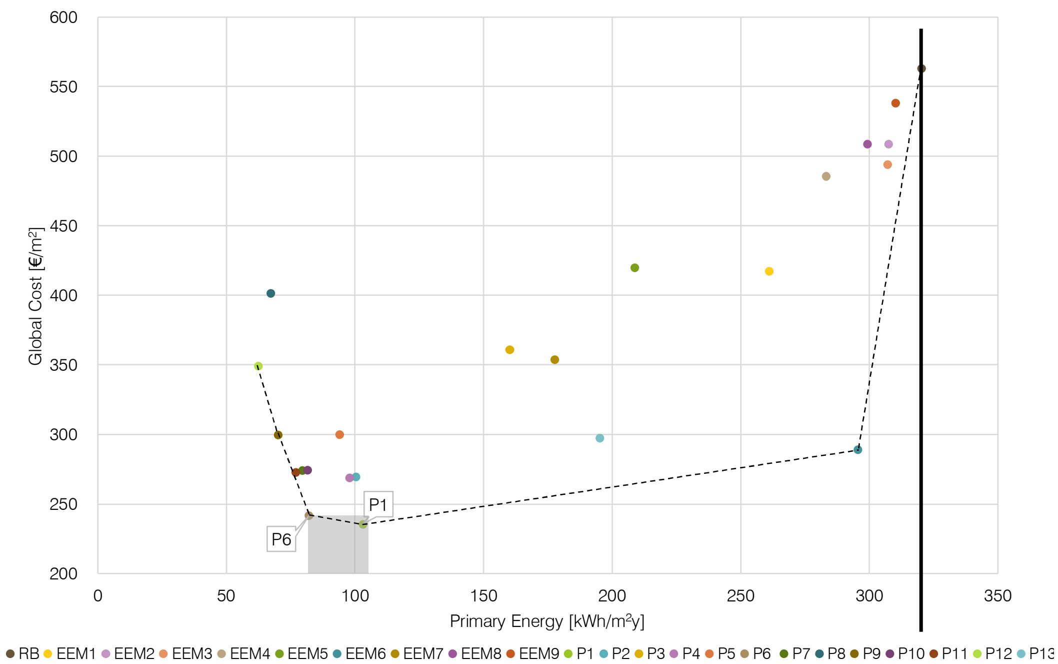


Figure 4-30: Cost-optimal graph for Case study 2. Source: (Carbone 2014)

4.4.3 Case study 3

The analysis of Case study 3 was object of another Master Thesis discussed at Politecnico di Torino (Riccadonna 2014) and supervised by the author.

Building features

The main features of Case study 3 are recalled in Table 4-33, while Table 4-34 and Table 4-35 give an overview on the envelope and systems properties respectively.

Table 4-33: Case study 3's main records

Location	Valloriate (HDD = 3288)
Hotel type	Mountain
Hotel Category	3*
Building typology	Multi-storey building
N° of floors	3
Occupancy	Opening period: all year. Occupancy rate: n.d.
N° of Staff members	2
Year of construction / refurbishment	1973 / 2001
Heated floor area	858 m^2
Heated volume	2390 m^3
N° of guestrooms	22
N° of beds	44

Table 4-34: Case study 3's envelope thermal features

Envelope Element	**Description**	**U-value [W/m²K]**
Roof	Pitched roof, with reinforced brick-concrete slab, low insulation	2,20
Floors to non-heated areas	Reinforced brick- concrete slab	1,30
External walls	Cavity walls with hollow-brick masonry (40 cm)	1,10
Walls to non-heated areas	Hollow-brick masonry (40 cm)	1,13
Ground Floor Basement	Concrete floor on ventilated cavity	1,80
Windows	Single-plane glass, wooden frame	3,95
	Single-plane glass, aluminium frame with no thermal break	5,77
	Low-e double pane glass, thermally improved PVC frame	1,67
	Double pane glass, wooden frame	2,17

Table 4-35: Case study 3's system features

System	Features			
	Generation	Storage	Distribution	Emission
Heating system	Diesel boiler	-	Centralized, vertical columns distribution	Cast-iron radiators
DHW	Diesel boiler	-	Centralized, vertical columns distribution	-
Mechanical ventilation	Air Handling Units serving common areas in the basement			

Energy analysis assumptions

As for the other case studies, the energy performances under investigation are those prescribed by the Italian D.Lgs. 192/2005, in force when the analysis was carried out. Building configurations were modeled in Termolog energy simulation software[9]. Termolog is a commercial software very popular among design companies, in line with nationally imposed regulations and calculation methods. Therefore, based on decree D.Lgs. 192/05, heating and DHW production were the only considered energy uses.

Financial analysis assumptions

The global cost formula items were defined as follow:

- C_I (investment cost) only included construction costs, which were derived from Piedmont Price List 2013 (Regione Piemonte 2012)
- C_m (maintenance costs) were calculated as percentages of the related initial investment cost, based on the indicative data given in Annex A of EN15459.
- C_e (energy costs) were assumed constant during the calculation period, equal to 0,131 €/kWh for diesel oil, to 0,09 €/kWh for natural gas a to 0,173 €/kWh for electricity, as derived from the hotel's bills;
- C_o (other operational costs) and C_{ad} (added costs) were excluded from the calculation.

[9] http://www.logical.it/software_termolog.aspx

- V_n (replacement costs) were quantified based on construction costs given in Piedmont Price List 2013 and on the estimated lifespan of building components provided in Annex A of EN 15459
- C_d (disposal costs) were not included in the calculation;
- R_R (real discount rate) was set to 3%;
- τ (calculation period) was set to 20 years, following Regulation N° 244/2012 precepts.

Energy Efficiency Measures and packages

The energy and financial performance of Case study 3 were first assessed for its original configuration:

- EP_{gl}= 300 kWh/m^2·y
- C_G = 982 €/m^2.

Then, technically feasible retrofit possibilities of the baseline model were defined in order to achieve energy savings through the improvement of the building envelope properties and of the building systems efficiency and through the exploitation of Renewable Energy Sources (RES). Dealing with envelope-related measures, for each intervention different thermal performance levels were investigated, where the lowest always represent by the minimum binding requirements.

Table 4-36 lists the single Energy Efficiency Measures and in Table 4-37 the packages of measures selected for the cost-optimal analysis are presented. Only packages reducing the primary energy index by at least 40% were considered for the cost-optimal analysis.

Table 4-36: Envisaged EEMs for Case study 3

EEM cat.	Element	Description	Code	EP_{gl}	Energy savings	C_G	C_I
				kWh/m²	%	€/m²	€/m²
Envelope	Ext. walls	Ext. insulation (U<0,33 W/m²K)	1.1	245	17%	863	41,5
		Ext. insulation (U<0,25 W/m²K)	1.2	245	18%	364	56,2
		Ext. insulation (U<0,15 W/m²K)	1.3	239	20%	371	65,2
	Walls to non-heated areas	Int. insulation (U<0,80 W/m²K)	2.1	295	2%	322	5,8
		Int. insulation (U<0,30 W/m²K)	2.2	292	3%	323	7,9
		Curtain walling (U<0,20 W/m²K)	2.3	292	3%	325	9,6
	Roof	Top-surface insulation (U<0,30 W/m²K)	3.1	267	11%	922	30,2
		Top-surface insulation (U<0,23 W/m²K)	3.2	265	12%	924	35,9
		Top-surface insulation (U<0,15 W/m²K)	3.3	263	12%	929	48,4
	Floors to non-heated areas	Insulation (U<0,80 W/m²K)	4.1	298	1%	982	6,7
		Insulation (U<0,26 W/m²K)	4.2	296	2%	978	9,2
		Insulation (U<0,17 W/m²K)	4.3	294	2%	976	10,9
	Ground Floor basement	Insulation (U<0,30 W/m²K)	5	283	6%	955	20,9
	Glazing	Substitution (U_w<2,00 W/m²K)	6.1	305,52	-		
		Substitution (U_w<1,50 W/m²K)	6.2	294	2%	1068	99,3

		Substitution (U_w<1,20 W/m^{2}K)	6.3	292	3%	1080	120,5
Plants and systems	Heating system	Installation of fan coils	7	285	5%	1058	63,5
	Heating plant	Installation of condensing boilers	8.1	245	17%	698	24,5
		Installation of air-to-water heat pump	8.2	Examined in combination with 40 ST panels			
	Ventilation	Installation of mechanical ventilation units and heat exchanger	9	Examined in combination with 28 m^2 of PV panels			
Renewable energy sources	ST panels	ST panels exposed E & W, covering 60% of DHW energy need	10.1	282	6%		
		ST panels exposed E and W, covering 100% of DHW energy need	10.2	277	8%		
	PV panels	PV panels 28 m^2 3 kWp	11.1	Examined in combination with Mechanical Ventilation			
		PV panels 112 m^2 14 kWp	11.2	300	1%		

Table 4-37: Packages of EEMs created for Case study 3

Code	Interventions
EEM1a	1.1 + 3.1 + 5 + 6.2 + 8.1
EEM1b	1.1 + 3.1 + 5 + 6.2 + 8.2 + 10.2
EEM1c	1.1 + 3.1 + 8.1
EEM2a	1.2 + 2.2 + 3.2 + 4.2 + 6.2 + 7 + 8.1
EEM2b	1.2 + 2.2 + 3.2 + 4.2 + 6.2 + 8.2 + 10.2
EEM3a	1.3 + 3.3 + 5 + 6.3 + 7 + 8.1 + 9 + 11.1
EEM3b	1.3 + 3.3 + 5 + 6.3 + 8.2 + 10.2 + 9 + 11.1
EEM4	1.2 + 3.2 + 4.2 + 6.3 + 8.2 + 10.2
EEM5	8.2 + 10.2
EEM6a	1.2 + 2.3 + 3.1 + 4.3 + 6.2 + 8.1 + 10.1
EEM6b	1.2 + 2.3 + 3.1 + 4.3 + 6.2 + 8.1 + 10.1 + 9 + 11.1
EEM7	7 + 8.2 + 10.2 + 9 + 11.1
EEM8a	1.3 + 2.3 + 3.3 + 4.3 + 5 + 8.1 + 9 + 11.1
EEM8b	1.3 + 2.3 + 3.3 + 4.3 + 5 + 8.1 + 10.1 + 9 + 11.1
EEM9a	1.3 + 3.3 + 6.3 + 7 + 8.1 +
EEM9b	1.3 + 3.3 + 6.3 + 8.2 + 10.2 + 11.2
EEM10	2.3 + 4.3 + 6.3 + 7 + 8.1 + 10.1 + 9 + 11.1

Cost-optimal graph

Based on the assumptions of this analysis, the obtained cost-optimal range of energy performance is rather wide. As Figure 4-31 shows, two packages of measures lie in the lowest part of the curve: EEM1c and EEM8a. Package EEM1c has the less significant reduction in EP_{gl}, as it includes only interventions satisfying the minimum level of thermal performances for external walls and roof and the substitution of the diesel boilers with condensing ones. The low investment costs are major contributors to the convenient global cost. On the opposite side of the cost-optimal range lies package EEM8a, where, by contrast, high performing envelope solutions are combined with condensing boilers, mechanical ventilation, heat exchanger and PV panels. The high energy savings obtained in this design hypothesis counterbalance the high investment costs and allow this option to be cost-optimal.

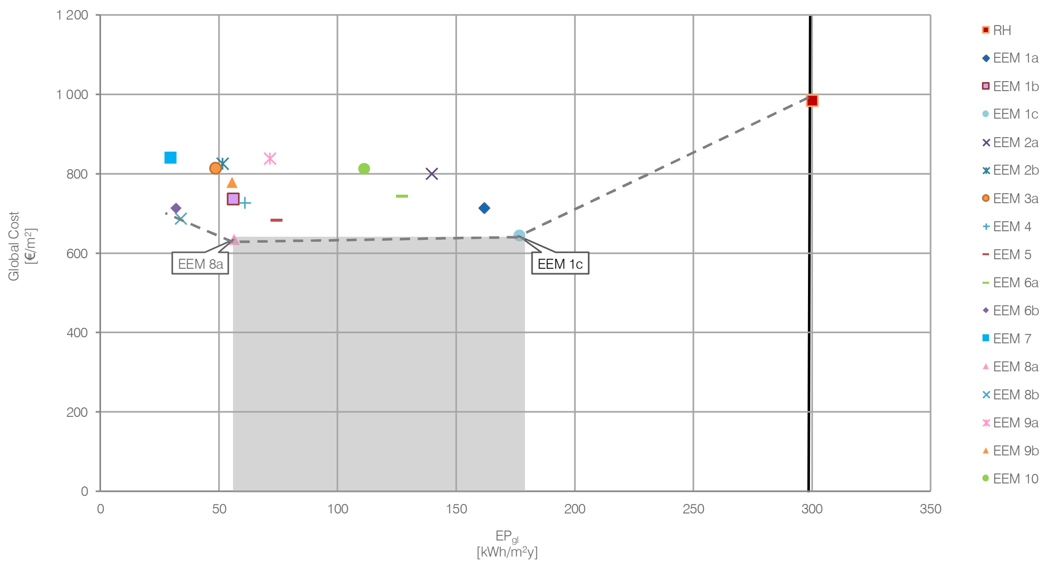


Figure 4-31: Cost-optimal graph for Case study 3. Source: (Riccadonna 2014)

4.4.4 Case study 4

Case study 4 was one of the actual Italian pilot cases of the neZEH project. Buildings' data derive from the energy audit and the feasibility study performed by SITI research institute in the context of the project and they were used to develop a cost-optimal analysis, aiming at guiding the hotel owners in their choices. Results were also object a publication co-authored by the PhD candidate, which is enclosed to this dissertation as Paper VIII.

Building features

Case study 4 is a family business hotel located in a central area of Turin. It is an historical building, subjected to some constraints in case of renovation. Not the whole building is dedicated to accommodation functions: the top floor hosts 2 private flats. The main data about the hotels are listed in Table 4-38 with the main envelope and systems features are summarized in Table 4-39 and in Table 4-40 respectively.

Table 4-38: Case study 4's main records

Location	Turin (HDD = 2617)
Hotel type	Urban
Hotel Category	
Building typology	Multi-storey building
N° of floors	6 (of which a half-basement area)
Occupancy	Opening period: all year Jan. – Mar.: 50-75% ; Apr. – June: 50-75%; July – Sept.: 50-75% ; Oct. – Dec.: 75-100%
N° of Staff members	4
Year of construction / refurbishment	1910 / 2005
Heated floor area	1138 m^2
Heated volume	3420 m^3
N° of guestrooms	20
N° of beds	78

Table 4-39: Case study 4's envelope thermal features

Envelope Element	**Description**	**U-value [W/m^{2}K]**
Floors to non-heated areas	Reinforced brick-concrete slab	1,30
External walls	brick masonry (55 cm)	1,12
Walls to non-heated areas	brick masonry (45 cm)	1,26
Ground Floor Basement	Concrete floor on soil	0,72
Windows	Double pane glass, wooden frame	2,6

Table 4-40: Case study 4's system features

System	Features			
	Generation	**Storage**	**Distribution**	**Emission**
Heating system	2 condensing boilers (installed in 2004)	How water storage tank	Centralized, vertical columns distribution	Fan-coils
DHW		How water storage tank for centralized hot water production	Centralized, vertical columns distribution	-
Cooling	Chiller with cooling tower			Fan-coils

Energy analysis assumptions

This analysis was specifically performed striving to reach the NZEB goal imposed by the neZEH project, which required energy uses for heating, DHW, cooling, lighting and appliances to be in the calculation. To this purpose, building configurations were modeled in SEAS energy simulation tool[10]. SEAS is an energy auditing software that can simulate residential, office, school, and hospital buildings, providing energy requirements for heating, domestic hot water production, ventilation, lighting, and other electrical uses.

Financial analysis assumptions

The global cost formula items were defined as follow:

- C_I (investment cost) only included construction costs, which were derived from Piedmont Price List 2015 (Regione Piemonte 2014);
- C_m (maintenance costs) were calculated as percentages of the related initial investment cost, based on the indicative data given in Annex A of EN15459;
- C_e (energy costs) were assumed constant during the calculation period, equal to 0,063 €/kWh for natural gas a to 0,19 €/kWh for electricity, as derived from the analysis of the hotel's bills;
- C_o (other operational costs) and C_{ad} (added costs) were excluded from the calculation.

[10] http://www.enea.it/it/Ricerca_sviluppo/ricerca-sistema-elettrico/efficienza-per-gli-immobili-della-pa/software-seas/richiesta-software-seas3

- V_n (replacement costs) were quantified based on construction costs given in Piedmont Price List 2013 and on the estimated lifespan of building components provided in Annex A of EN 15459
- C_d (disposal costs) were not included in the calculation;
- R_R (real discount rate) was set to 3%;
- τ (calculation period) was set to 20 years, following Regulation N° 244/2012 precepts.

Energy Efficiency Measures and packages

The energy and financial calculations were first developed for the case study in its original configuration, resulting in:

- EP_{gl}= 266 kWh/m^2·y
- C_G = 343 €/m^2.

In order to reduce the energy performances towards the neZEH target, bespoke energy efficiency measures were considered by taking into account the preliminary energy evaluation of the case study, the context, the building typology and the owners' point of view. The proposed options are listed in Table 4-41. Blending EEMs, packages of retrofit interventions were proposed, as summarized in Table 4-42.

Table 4-41: Envisaged EEMs for Case study 4

Description	Code
External walls insulation (10 cm insulation layer)	EEM1
External walls insulation (23 cm insulation layer)	EEM2
Windows substitution with low-e triple pane glass and thermally improved aluminium frame	EEM3
Water saving devices	EEM4
Connection to district heating	EEM5
Stand-by reduction	EEM6
Induction cookers	EEM7
LED lights	EEM8
Installation of Solar Thermal (ST) Panels (50 m^2, 76% DHW need)	EEM9
Installation of Solar Photovoltaic (PV) Panels (36 m^2)	EEM10

Table 4-42: Packages of EEMs created for Case study 4

Code	Interventions
Int. 1	EEM4 + EEM6
Int. 2	EEM4 + EEM6 + EEM7 + EEM8
Int. 3A	EEM4 + EEM6 + EEM7 + EEM 8 + EEM9
Int. 4A	EEM1 + EEM3 + EEM4 + EEM6 + EEM7 + EEM 8 + EEM9
Int. 3B	EEM4 + EEM5 + EEM6 + EEM7 + EEM 8
Int. 4B	EEM1 + EEM3 + EEM4 + EEM5 + EEM6 + EEM7 + EEM 8
Int. 5B	EEM4 + EEM5 + EEM6 + EEM7 + EEM8 + EEM10
Int. 6B	EEM2 + EEM3 + EEM4 + EEM5 + EEM6 + EEM7 + EEM8 + EEM10
Int. 1C	EEM4 + EEM9
Int. 2C	EEM4 + EEM5
Int. 1D	EEM6 + EEM8
Int. 2D	EEM6 + EEM7 + EEM8
Int. 3D	EEM6 + EEM7 + EEM8 + EEM10
Int. 4D	EEM4 + EEM6 + EEM7 + EEM8 + EEM10

Cost-optimal graph

Figure 4-32 shows the results of the cost-optimal analysis. Primary energy results for retrofit interventions are plotted versus the calculated global cost and vertical lines points out the gap between the baseline building primary energy use and the Italian benchmark for nearly Zero Energy Hotels defined by neZEH project. No package of EEMs was able to reduce the primary energy use to the desired target. Indeed, the peculiarities of the structure made neZEH target too ambitious. The most evident “real life” constraints for the implementation of retrofit measures are related to the building envelope.

In this case, the cost-optimal level of energy performance was represented by a design option that lowered the original building energy use by less than 13%, reaching a primary energy use of 233 kWh/m^{2}y. The considered option includes non-invasive EEMs, devoted to reduce lighting and appliances electricity consumptions and water usage.

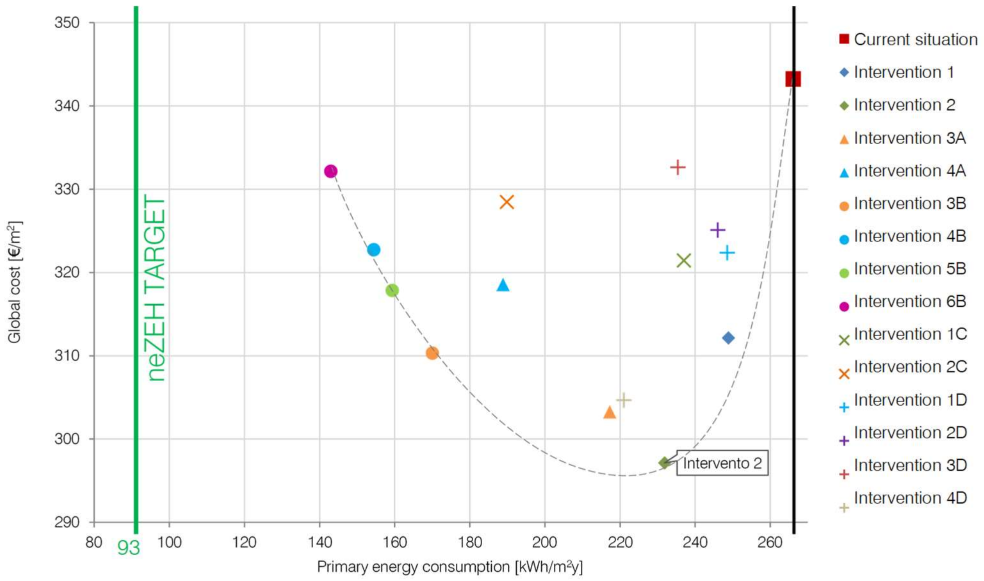


Figure 4-32: Cost-optimal graph for Case study 4. Source: (Corino et al. 2015)

4.4.5 Comparative analysis and discussion

Main goal of this section was to combine the outcomes of different studies in order to investigate the possible common patterns in terms of cost-optimal energy performance levels and/or of typical energy efficiency measures. In Figure 4-33, global costs and primary energy indexes of the cost-optimal packages of EEMs of the four case studies are plotted together. In Table 4-43, instead, the energy efficiency measures included in the cost-optimal packages of EEMs are recalled.

Going through the different energy analysis assumptions, it stands clear for the reader that a coherent comparison among cost-optimal energy performance levels for the different case studies is impossible to perform. Beside the obvious differences between case studies' features, different quasi-stationary simulation tools were used and different end-uses were included in the calculations. Specifically, while case studies 1 to 3 only dealt with heating and DHW end-uses, Case study 4 included also cooling and electricity consumptions in the calculation of primary energy uses. This mismatch heavily influenced the selection of energy efficiency measures to be considered cost-optimal. In case studies from 1 to 3, EEMs related to the envelope thermal improvement and to plants substitutions are cost-optimal, while in Case study 4 low-invasive measures reducing the hotel electricity use resulted as the most convenient. Cost-optimal levels of energy performance are very different from one case to the other as well. Once again, the inclusion of heating and DHW end-uses only, deeply influenced the results. Cost-optimal solutions for case studies 1 to 3 reduced the primary energy index by more than 30% with respect to their original configurations in all cases. Conversely, when all energy uses are considered (case 4), the cost-optimal level of primary energy use reduced the baseline performance by just 12%.

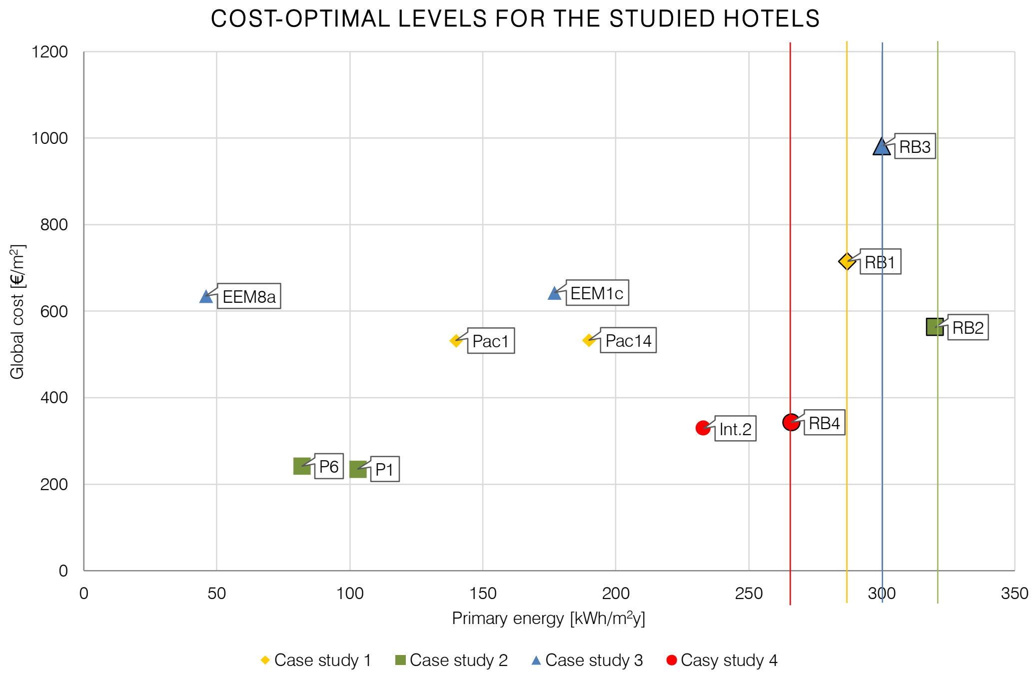


Figure 4-33: Primary energy indexes and global costs of the cost-optimal solutions of the 4 analyzed case studies

Table 4-43: EEMs included in the cost-optimal retrofit solutions of the 4 case studies

<table>
<tr><th>Case study</th><th>C-O packages</th><th>EEMs included</th></tr>
<tr><td rowspan="2">Case study 1</td><td>Pac1</td><td>- High insulation levels for external walls
- High insulation level for the roof
- Air-to-water heat pump</td></tr>
<tr><td>Pac14</td><td>- Air-to-water heat pump
- Solar thermal panels
- Photovoltaic panels</td></tr>
<tr><td rowspan="2">Case study 2</td><td>P1</td><td>- Insulation levels by law for external walls
- Insulation levels by law for walls to un-heated areas
- Insulation levels by law for the roof
- Condensing boilers</td></tr>
<tr><td>P6</td><td>- Insulation levels by law for external walls
- Insulation levels by law for walls to un-heated areas
- Insulation levels by law for the roof
- Condensing boilers
- Solar thermal panels</td></tr>
<tr><td rowspan="2">Case study 3</td><td>EEM1c</td><td>- Insulation levels by law for external walls
- Insulation levels by law for the roof
- Condensing boilers</td></tr>
<tr><td>EEM8a</td><td>- Very high insulation levels for external walls
- Very high insulation levels for walls to un-heated areas
- Very high insulation levels for the roof
- Very high insulation levels for floors to un-heated areas
- Insulation levels by law for basement ground floor
- Condensing boilers
- Mechanical ventilation
- Solar thermal panels
- Photovoltaic panels</td></tr>
<tr><td>Case study 4</td><td>Intervention 2</td><td>- Water saving devices
- Stand-by reduction
- Induction cookers
- LED lights</td></tr>
</table>

Based on these outcomes, several critical remarks arise, in view of moving towards a more effective valuation method of possible retrofit options for hotel buildings, and commercial buildings in general. First, results made evident that for hotel buildings the inclusion of energy uses related to space heating and domestic hot water needs provided a misrepresented overview of their energy performances and their potential improvements. As only a fraction of the actual energy uses is taken into account, the expected energy savings should be weighted accordingly. Moreover, this limited point of view excludes from the range of potential EEMs a long list of solutions aimed at reducing the electricity energy uses. These consequences can easily be spotted in the different EEMs and energy performance levels between case studies 1 to 3 and Case study 4. By including all end-uses in the energy evaluation, results given by the cost-optimal analysis for Case study 4 are less optimistic. These issues are nowadays partly solved by the new Italian dispositions regarding minimum energy requirements and energy performance certificates (Presidente della Repubblica 2013; Ministero dello Sviluppo Economico 2015b), as at present the energy evaluation for non-residential buildings includes end uses for heating, DHW, cooling, ventilation, lighting and lift systems.

On the other hand, by considering all energy uses in these buildings (where electricity for lighting and appliances play a major role), the energy saving potential related to the retrofit of the building it-self may be considered by investors as a minor aspect. For instance, in Case study 4 mainly electricity-related EEMs are included in the cost-optimal design proposal. Given the strategic importance that the renovation of the existing building stock has in the fulfillment of the low-carbon goals, this circumstance should be avoided as well. The Italian regulation currently in force addresses this issue by imposing mandatory minimum requirements related to envelope and plants performances as a precondition for any major building renovation.

A trade-off between retrofit proposals that effectively reduce the energy costs of a hotel business and proposals that improve the energy performance of the building is the longed solution, able to boost an energy efficient renovation of the hotel building stock. However, based on results proposed in section 4.3, such retrofit options are still far from cost-optimality.

4.5 Key findings

Given the two research strategies pursued, cost-optimal methodology applied to a Reference Hotel and to real buildings, outcomes of this chapter are two-folded. However, they converge on similar conclusions. The analysis carried out for the Refence Hotel revealed that cost-optimal retrofit solutions do not fulfil the NZEB nor the minimum energy requirements, due to the relevant weight that electricity consumptions have in the overall energy use of the building. Nonetheless, NZEBs solutions for the RH had the best thermal comfort performances among the envisaged options. The analyses on real hotels revealed that the inclusion of all relevant energy flows, often non-mandatory in energy regulations, is a prerequisite for meaningful information on the potential energy saving in hotel businesses. Unfortunately, cost-optimal retrofit solutions may not include measures effectively improving the building energy performances (e.g. heating and cooling), due to the high share of electricity energy uses.

Therefore, both applications of cost-optimal methodology suggest that the mere implementation of an engineering approach to define a trade-off between short-term costs and long-term benefits (i.e. investment costs versus operation and maintenance costs, anticipated energy and carbon savings and residual value) does not answer to the growing need of boosting private investment towards energy efficient buildings. New valuation methods should be adopted. At the current stage, only reduced running cost and higher final value of the building are considered as assets for implementing retrofit measures. For boosting green private investments, extra benefits deriving from the renovation process, such as improved image of the building, new market positioning, increased guest comfort and satisfaction, should be included in the calculation methods.

Chapter 5

5. Introducing the economic perspective

5.1 Overview

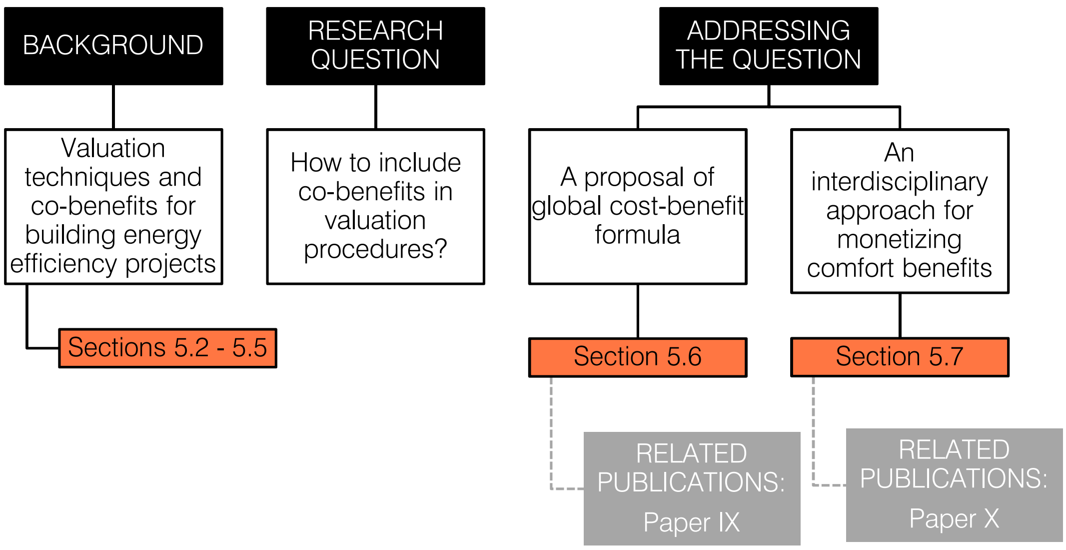


Figure 5-1: Schematic summary of Chapter 5's objectives and contents

Findings of the previous chapter, which suggest that high performing retrofit interventions are not financially convenient in non-residential buildings, are the starting point for the investigations presented in this last section of the PhD thesis. In this chapter, the proposition claiming that energy efficiency projects involve a much wider range of benefits than just reduced energy and emissions is fully embraced. In section 5.2 a hint on the effort put at the international level to promote this concept is provided. In accordance with literature (Ürge-Vorsatz et al. 2009; Kolstad et al. 2014; Ferreira & Almeida 2015), in this chapter the positive side-effects of energy efficiency measures on economic and social growth are defined as co-benefits. Many studies focused their efforts in identifying these co-benefits and in trying to quantify in monetary terms the side effects that these benefits bring to both investors and policymakers (see Section 5.5). However, the recognized existence of co-benefits is not mirrored in common valuation methods for buildings efficiency projects, briefly described in section 5.4. As highlighted in section 5.3, by omitting co-benefits the risk is to further widen the so-called "energy efficiency gap" (Howarth 2004), which is the chasm between the generally known advantages brought by energy efficient technologies ant the little enthusiasm shown by the market towards these technologies.

Aiming at boosting investments in energy efficiency projects for buildings, the research question that this thesis attempts to answer is:

How to include co-benefits in valuation procedures?

Possible solutions followed two different strategies. First, in section 5.6, it was proposed to exploit findings from existing studies proposing co-benefits monetization, in order to include these monetary values in the global cost formula. Then, in section 5.7, the issue of monetizing non-market co-benefits was faced directly, by proposing a multidisciplinary (engineering-economic) approach to valuate comfort costs and benefits. As the monetary value of any co-benefit is sensitive to the context of the analysis, both proposals were applied to specific case studies. Specifically, hotel buildings were again elected as target category because of their service-oriented nature. Indeed, hotel guests are proved to be sensitive to non-energy benefits such as optimal comfort conditions (Qi et al. 2017) or green attitudes (Kuminoff et al. 2010) and their appreciation can have direct consequences on the business success of the hotel (i.e. increased market appreciation and competitiveness).

Based on this overview, in Figure 5-1 the structure of the chapter is outlined.

5.2 Promoting energy efficiency in buildings

Due to the crucial role that Europe has attributed to energy efficiency in buildings towards the low-carbon transition, the link between environmental and financial performance of the real estate sector is nowadays a hot topic among researchers and practitioners, among public and private institutions. Not by chance, energy efficiency has been elected by finance and energy experts as “first fuel” for European economy (EEFIG 2015). In order to drive market decisions towards realizing the energy saving potential, the international community is funding several projects focused on proving the financial profitability of energy efficient new and retrofitted buildings. As an example, the international research project Annex 56[11] is about cost-effective energy and carbon emission optimization in building renovation. At the EU level, RentalCal and Total Concept projects can be mentioned. RentalCal project[12] aims at assessing the impacts of energy efficiency refurbishments of existing buildings on landlords’ cash flows building value and profitability; Total Concept project[13] offers a method and a financial tool to offer to investors rationales for major reduction of energy use in commercial buildings.

Encouraging signals of the inclusion of environmental concerns in private businesses can be spotted. The list of investors taking part in voluntary initiatives and associations that focus on the role of real estate in climate risk has significantly extended in the last decade. The voluntary scheme Principles for Responsible Investment Institution[14] (PRI) dates back to 2006 and has nowadays more than 1500 signatories worldwide among asset owners, investment managers and service providers. Its goal is to understand the investment implications of environmental, social and governance issues and to support its network in investments decisions. At the European level, the investors’ voice on climate solutions is the Institutional Investors Group on Climate Change[15] (IIGCC). It is a network of more than 120 members, including some of the largest pension funds and asset managers, who have as a relevant focus the integration of climate risk in real estate investment practice. In this view, the UNEP FI report on Sustainable Real Estate Investments (Bosteels & Sweatman 2016), released after COP21 decisions, provides an action

[11] More information available at http://www.iea-annex56.org/
[12] More information available at http://www.rentalcal.eu/
[13] More information available at http://totalconcept.info
[14] More information available at https://www.unpri.org/
[15] More information available at http://www.iigcc.org

framework for property investors to include environment, social governance and climate risk into real estate investment decisions.

5.3 The energy efficiency gap and paradoxes

Despite the shift toward a low-carbon economy is clear in terms of global trends and intentions, there is a quite evident dichotomy between ambitious legislative goals and partly unsatisfactory real-life outcomes. Even if the technical feasibility of high performing building, reaching the nearly zero energy level and beyond, has been proved by many case studies (Ascione, Bianco, Bottcher, et al. 2016; Zhou et al. 2016) investments in energy efficient buildings are still far below their potential. Profitability of investments related to energy efficiency in buildings is a relevant issue to be addressed order to boost action in this sector. This phenomenon is known in energy-related literature as the “energy efficiency gap”, for which three main possible interpretations are documented: “hidden costs” of the interventions, too high discount rates expected by investors and stakeholders’ “bounded rationality”, often due to a simplistic approach to the investment decisions (Howarth 2004).

Particularly, market surveys revealed that practitioners’ concerns are related to the construction costs of green buildings, perceived to be significantly higher than that of a conventional counterpart (Issa et al. 2010; Liang et al. 2014). Despite the significance of the problem, empirical investigations addressing the issue of green cost premium are still very limited and conflicting in their findings, as Dwaikat and Ali claim as a result of a systematic literature review on the topic (Dwaikat & Ali 2016).

In the appraisal and energy research fields, several studies have been conducted for assessing the viability of sustainable real estate investments. In these studies, the valuation methodologies typically involve a trade-off between short-term costs and long-term benefits by applying an engineering approach (Howarth 2004), that, in buildings, accounts for investment costs, operation and maintenance costs, anticipated energy and carbon savings and residual value. The global cost formula well exemplifies this method. However, in these calculations, energy efficiency paradoxes related to the operational life of buildings, such as the re-bound and pre-bound effect, may dampen the predictions of savings related to the implementation of energy efficiency measures. Re-bound and pre-bound effects both build on the gap between predicted and actual energy performances of buildings, with a particular focus on the role of occupants. The re-bound effect, also known in economic theory as the Jevons paradox, is well recognized in energy-efficiency related literature (Khazzoom 1980; A. Greening et al. 2000; Sorrell & Dimitropoulos 2008). It refers to the empirical evidence for which many energy efficiency improvements do not reduce energy consumption by the amount predicted by simple engineering models, because such improvements make energy services cheaper, so that consumption of those services increases. In case of building retrofit, for instance, the re-bound effect occurs when a proportion of the energy savings is consumed to satisfy increased comfort expectations or when the related financial savings are spent in new appliances (Sorrell & Dimitropoulos 2008). However, the sources and size of the re-bound effect is still object of debate. Depending on the definition used for the re-bound, the size of this effect can be either insignificant or can result in an increase in fuel consumption. In any case, its influence on the profitability of an energy efficiency interventions has to be taken into account. By contrast, the pre-bound effect indicates how much less energy is consumed than expected. The concept of pre-bound effect was proposed for the first time by Sunikka-Blank and Galvin, specifically referring to energy retrofits (Sunikka-Blank & Galvin 2012). The comparison between datasets of energy performance certificates (EPC) and measured energy use data for the same sets of residential buildings showed that calculated energy performances from EPCs were inversely proportional to measured energy uses. These findings suggested that “the worse a home is thermally, the more economically the occupants tend to behave with respect to their space heating”. Since retrofits cannot save energy that is not actually being used, the economic viability of retrofits may be reduced by this effect.

5.4 Valuation methods

Generally speaking, valuation techniques for energy efficiency projects can be divided based on the financial or economic perspective (Prizzon 2001). The financial perspective considers the immediate effects of the investment decision; the economic standpoint takes into account all costs and benefits that are triggered by the energy efficiency investment and that have an impact on other market actors than the investor. Both the valuation approaches are crucial to the low-carbon transition. From the financial standpoint, research and public authorities share the same investigative goal as practitioners and private investors: to assess whether energy efficiency measures in buildings are viable. However, the reasons for the investigation are different. For researchers and public authorities, the financial feasibility of energy efficiency projects is the trigger to boost private investments.

Indeed, as stated by the Energy Efficiency Financial Institutions Group, in Europe there is urgent need to scale up the energy efficiency investment, that should be addressed by a historic level of public-private collaboration (EEFIG 2015). For practitioners and private investors, the reasons are more tangible and related to their business success. The economic perceptive, instead, strives to capture societal direct and indirect costs and benefits. Economic evaluations are of interest of public authorities, rather than of private investors, as they have the huge potential to drive local and global policies toward the most beneficial (low carbon, environmentally friendly) development paths.

Typically, financial valuation refers to the Discounted Cash Flow method (DCF), while economic valuation refers to Cost-Benefit Analysis (CBA) (Prizzon 2001). In-between, Global Cost is the EU-suggested economic indicator for the evaluation of building energy retrofit projects, that consider the financial or economic perspective based on the items included in the calculation.

These valuation approaches to energy efficiency interventions strongly relate to the issues highlighted in section 5.3. The valuation methodologies to deploy economic and financial strategies for enhancing energy efficiency usually pass through the Net Present Value (NPV) criterion and traditional discounting procedures. In this valuation mechanism, high investment-savings ratio, energy price fluctuation and energy inflation rate have huge relevance in determining the viability of an intervention. Rebound and pre-bound effects can deeply influence the expected energy savings. In addition to this, as spotted by Copiello and Bonifaci (Copiello & Bonifaci 2015), energy price and inflation rate variables may cause in the future the rise of a new energy efficiency paradox. In an efficient market, if energy efficiency measures reduce the buildings dependence to energy supply, the energy prices are expected to reduce, or at least to stabilize over the medium-long term. The paradox is that the market uptake of energy efficient buildings could reduce the profitability of the self-investments, because of the lower energy prices and prices fluctuation. This phenomenon, together with the fact that the investments-savings ratio of high performing interventions boldly increases with the improvement of the expected performance, may act as a disincentive for further upgrading of buildings.

As a possible answer to these concerns, in recent years Multiple Criteria Decision Analysis (MCDA) emerged as an alternative non-monetary approach to evaluate the consequences of complex investment decisions such as retrofit actions (Wang et al. 2009).

In the followings, based on relevant references (Prizzon 2001; Fregonara 2015; Clinch 2004; Sartori et al. 2014; Zopounidis & Doumpos 2017), a brief description of each of the mentioned methods is provided, with special attention to their application to energy efficiency projects.

5.4.1 Discounted Cash Flow Method

A discounted cash flow (DCF) is a valuation method used to estimate the attractiveness of an investment opportunity. DCF analysis uses future cash flow projections for given time periods and discounts them to arrive at a present value estimate, which is used to evaluate the potential for investment.

Cash flows are given by the difference between revenues and costs occurring at any considered time period and may or may not include taxation. Real estate investors revenues typically include sales or rents, while investment and management costs are the most common outflows. Through the discount rate, these cash flows are actualized to their present values. The difference between the present value of cash inflows and the present value of cash outflows is the Net Present Value (NPV), which is a main profitability index in the DFC method. Indeed, the profitability of an investment is acceptable if the NPV is positive. In order to further investigate the profitability of the investment, the Internal Rate of Return (IRR) has to be calculated. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a project equal to zero. In practical terms, it indicates the level of investments for which positive and negative cash flows are balanced. Profitable investment projects require IRR higher than the discount rate used for actualization and higher than investor's profitability expectations. Pay Back Period (PBP) is another popular profitability index. The Pay Back Period (simple or discounted) gives the number of years it takes to break even from undertaking the initial expenditure. It is a less accurate indicator than the previous ones as it excludes for the evaluation cash flows after the break-even moment, but it gives immediate insights to investors. The lower the PBP, the more profitable the investment.

In view of applying the DCF method to energy efficiency project in buildings, the model requires detailed information, to evaluate the effect that different retrofit strategies have on investment, operation & maintenance costs and possible revenues. On the other hand, additional outputs are needed to express the energy and financial convenience of projects proposal (e.g. indexes evaluating the energy performance in relation with PBP) (Fregonara 2015).

The study by Christersson et al. (Christersson et al. 2015) well exemplifies the use of IRR, PBP and DFC to understand the embedded economic gains that energy efficiency improvements can provide for the property investor. By analyzing the financial performances of 29 Finnish office buildings the authors proved the significant financial potential embedded into building energy retrofit.

5.4.2 Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) is an analytical tool for judging the economic advantages or disadvantages of an investment decision by assessing its costs and benefits in order to assess the welfare change attributable to it. The rationale of CBA lies in the observation that investment decisions taken on the basis of profit motivations and price mechanisms lead, in some circumstances (e.g. market failures such as asymmetry of information, externalities, public goods, etc.), to socially undesirable outcomes.

The analytical framework of CBA refers to a list of underlying concepts:

- **Opportunity cost**. The opportunity cost of a good or service is defined as the potential gain from the best alternative forgone, when a choice needs to be made between several mutually exclusive alternatives. If inputs, outputs (including intangible ones) and external effects of an investment project are valued at their social opportunity costs, the return calculated is a proper measure of the project's contribution to social welfare.
- **Long term perspective**. A long-term outlook is adopted, ranging from a minimum of 10 to a maximum of 30 years or more, depending on the sector of intervention. The far time horizon requires to forecast future costs and benefits, to adopt appropriate discount rates and to take into account uncertainty by assessing the project's risks.
- **Calculation of economic performance indicators expressed in monetary terms**. CBA is based on a set of predetermined project objectives, giving a monetary value to all the positive (benefits) and negative (costs) welfare effects of the intervention. Many valuation techniques arise in cost-benefit analysis, and most cost-benefit studies draw on a pool of experience of methods and actual values to complete their analysis. The obtained monetary values are discounted and then totalled in order to calculate a net total benefit. The project overall performance is measured by indicators, namely the Economic Net Present Value (ENPV), expressed in monetary values, and the Economic Rate

of Return (ERR), allowing comparability and ranking for competing projects or alternatives.

- **Incremental approach**. CBA compares a scenario with the project with a counterfactual baseline scenario without the project. The incremental approach requires that the creation of a counterfactual scenario is defined as what would happen in the absence of the project. For this scenario, projections are made of all cash flows related to the operations in the project area for each year during the project lifetime. In cases of investments aimed at improving an already existing facility, it should include the costs and the revenues/benefits to operate and maintain the service at a level that it is still operable (business as usual) or even small adaptation investments that were programmed to take place anyway (do minimum). Projections of cash flows are made for the situation with the proposed project and for the without-project scenario, where both the financial projections are based on historical costs and revenues of the beneficiary. Give the project alternatives and the counterfactual scenario, CBA only considers the difference between their cash flows. The financial and economic performance indicators are calculated on the incremental cash flows only.

CBA is typically an economic approach enabling the assessment of a project's impact on society as a whole via the calculation of economic performance indicators, thereby providing an assessment of expected welfare changes. Coming to building retrofit projects, the European Commission CBA guide (Sartori et al. 2014) identified typical economic benefits to be included analysis, beside the traditional occurring costs:

- Increase of consumption efficiency;
- Increase of comfort;
- Reduction of GHG emissions;
- Reduction of air pollutant emissions.

Araújo et al. (Araújo et al. 2016) proposed cost-benefit analysis at the building level as an alternative to the cost-optimal methodology. By plotting in a by-dimensional graph the differences in life cycle costs and life cycle energy performances relative to various retrofit options for a case study, the authors enabled the graphical display of stakeholders' willingness to invest in energy efficient solutions.

5.4.3 Global cost

European Commission suggested global cost - in the framework of cost-optimal methodology - as the economic/financial feasibility indicator for building-related energy efficiency projects (European Commission 2012a). It relies on the NPV calculation principles and it takes into account the financial and economic perspectives by including different costs in the calculations. Specifically, the financial perspective takes into account investment, annual, and disposal costs, considering prices as paid by the end consumers (i.e. including taxes and possible subsidies). From the economic point of view, greenhouse gas (GHG) emissions costs are added to investment, annual and disposal ones, which in turn omit all applicable taxes and subsidies.

The EU-recommended global cost only includes energy-related costs, while positive cash flows are accounted in terms of residual value of the implemented measures at the end of the calculation period. In this view, the most profitable retrofit options are those reaching a winning trade-off between investment costs and avoided operational and GHG emissions costs. Indeed, cost-optimal methodology was born to define national minimum energy performance requirements and not inform stakeholders on the financial/economic profitability of energy efficiency projects. However, in line with EU suggestions, in recent years cost-optimality (and therefore global cost) was promoted as a preliminary decision-making tool to assess the convenience of energy efficiency options for specific case studies. The scale of application of the cost-optimality principles to case studies ranges from building elements (Pal et al. 2016), to the building as a whole up (Becchio, Dabbene, et al. 2015), to the district (Paiho et al. 2015).

The inclusion of financial and economic revenues related to energy efficiency interventions, in line with those included in the DFC and CBA valuation methods, could further strengthen the role of cost-optimality in driving stakeholders' decisional processes.

5.4.4 Multiple Criteria Decision Analysis

The Multiple Criteria Decision Analysis (MCDA) family include a series of valuation techniques with a common underlying trait, the ability to make a comparative assessment of alternative projects. These techniques cover a wide range of quite distinct approaches – in contrast with the uniform body of techniques of CBA – and they can be exploited for different purposes. They can identify a single most preferred option, rank options, short-list a limited number of options for subsequent detailed appraisal, or simply they can be used to distinguish acceptable from unacceptable possibilities.

Multi-criteria analysis establishes preferences between options by reference to an explicit set of objectives that the decision-making body has identified, and for which it has established measurable criteria to assess the extent to which the objectives have been achieved. In simple circumstances, the process of identifying objectives and criteria may alone provide enough information for decision-makers. A key feature of MCA is its emphasis on the judgement of the decision-making team in establishing objectives and criteria, estimating relative importance weights and, to some extent, in judging the contribution of each option to each performance criterion. Thanks to its human-based structure, MCA can bring a degree of structure, analysis and openness to classes of decision that lie beyond the practical reach of CBA. One limitation of MCA is that it cannot show that an action adds more to welfare than it detracts. Thus, in MCA the ‘best’ option can be inconsistent with improving welfare.

In its practical application, multi-criteria analysis starting point is a performance matrix, or consequence table, in which each row describes an option and each column describes the performance of the options against each criterion. The decision-making body assigns a score to the expected consequences of each option and it assigns numerical weights for the criteria. Numerical analyses are then applied to the so-defined performance matrix to give an overall assessment of each option being appraised.

Thanks to the ability of these methods to inform stakeholders about problems and possible alternative courses of actions without incurring in evaluative issues, they have great potential for applications to urban/district level energy efficiency projects, as proved for instance by the study by Becchio et al. on the Nearly Zero Energy retrofit possibilities for an Italian neighborhood (Becchio et al. 2017).

5.5 The potential of co-benefits

Real estate investments in energy efficiency are nowadays promoted as win-win opportunities for public and private investors (Næss-Schmidt et al. 2012; WGBC 2013). However, in section 5.3 the main weaknesses that could deteriorate the link between financial/economic and environmental performance of buildings were presented as intrinsic to the evaluation tools themselves.

The apparent incoherence between the successful investment scenarios proposed by the international organizations and the drawbacks of their economic/financial evaluation can be solved by taking into account non-energy benefits in the monetary valuation method previously listed. The International Energy Agency denounces that the traditional economic approach to project appraisal does not take into account what they define as "multiple benefits" (IEA 2014). Multiple benefits would allow the economic valuation to capture the impact that energy efficiency has across many different spheres of the global development, going beyond the reduced energy demand and lower greenhouse gas emissions. The Intergovernmental Panel for Climate Change embraces the same vision and indicates that such non-energy and non-climate benefits are especially large in the buildings sector (IPCC 2007). In recent years, many studies have pointed out that energy efficiency in buildings has the great potential to involve a much wider range of benefits, both at the macro and micro economic level (Kats 2006; Ürge-Vorsatz et al. 2009; Staniaszek 2013; IEA 2014; Kolstad et al. 2014). Some authors even suggest that the total value of these non-energy benefits may in fact exceed the direct benefits connected the investment (Kats 2006).

Table 5-1 lists and categorizes possible benefits (energy and non-energy) of energy efficiency interventions proposed in literature. As for valuation methods, in the table benefits were distinguished between financial and economic. The financial perspective considers the benefits of a building retrofit intervention from the investor's point of view. The economic benefits, instead, take into account the societal point of view and they were further categorized by the author into micro- and macro-economic. The first ones include the short-term effects of a building retrofit from the society's point of view, the latter ones have a long-term impact on society, being able to support policy makers in the development of energy related policies and to understand how building retrofits may impact other areas of policy action.

Table 5-1: Energy and non-energy benefits of energy efficiency interventions in buildings

Category	Sub- category	Financial	Economic		Ref.
			micro-	macro-	
Health Effects*	Reduced mortality		X	X	a,b
	Reduced morbidity	X	X	X	a,b
	Reduced physiological effects		X	X	a,b
Users' Wellbeing	Increased comfort		X	X	a,b,c,d,e
	Thermal comfort		X		a
	Lighting comfort		X		a
	Indoor Air Quality		X		a,b
	Noise level		X		a
	Pride, prestige, reputation		X		a
	Ease of installation and reduced annoyance		X		a
Environment/ Ecological Effects	Reduction of outdoor air pollution (CO_2/NO_x/SO_2)		X	X	a,b,e,f
	Construction and demolition waste reduction		X	X	a,b
	Increased urban vegetation (in case of new green walls/roof)		X	X	b
Building Quality	Building physics		X		a
	Aesthetics		X		a
	Ease of use		X		a
	Useful building area (in case it increases)	X	X		a
	Safety		X		a
Economic Effects	Energy Savings	X	X	X	b,d
	Water Savings	X	X	X	d
	Operation and Maintenance Savings	X			c,d
	Subsidies	X			
	Increased asset value	X			b,c,f
	Risk mitigation	X			c
	Regulatory risks	X			c
	Physical risks	X			c
	Market risks	X			c
	Technology risks	X			c
	Improved productivity	X	X	X	a,b,c,d,f

	Reduced exposure to energy price fluctuations	X		a
	Lower energy prices		X	a,b,f
	New business opportunities		X	a,b,e,f
	Employment creation		X	a,b,e,f
	Reduced outlay subsidies		X	a,b,e,f
	Higher lifetime earnings		X	b
	Lower bad debt write-off		X	b
	Avoided costs to support health, indoor environment and building facilities		X	b
Social/ Political Effects	Improved social welfare, reduced fuel poverty		X	a,b,f
	Increased awareness	X	X	b
	Improved energy security		X	b,f
	Increased political popularity		X	b
	Benefits to disadvantaged social groups		X	b
	Safety increase: fewer fires	X	X	b
Service Provision Benefits	Transmission and distribution loss reduction		X	b
	Fewer emergency service calls		X	b
	Utilities insurance savings		X	b

a (Ferreira & Almeida 2015)
b (Ürge-Vorsatz et al. 2009)
c (WGBC 2013)
d (Kats et al. 2003)
e (Næss-Schmidt et al. 2012)
f (IEA 2014)

While for energy-related benefits quantification and monetization are feasible tasks, non-energy benefits, here defined as co-benefits, are often not quantified, monetized or even identified by stakeholders. In particular, literature denounces quantification and consequent monetization as the most challenging tasks. Indeed, while the identification of co-benefits gives rather universal results among different studies, their translation in numerical values widely vary from one application to the other. To this extent, the comprehensive co-benefits review by Ürge-Vorsatz et al. (Ürge-Vorsatz et al. 2009) reveals that even a coherent comparison among the quantitative effects of the same co-benefit is hard to perform, due to different metrics and variables included. Nonetheless, the monetary value of co-benefits needs to be estimated in order to include these aspects in the decision process for investments in high performing buildings.

In this chapter, the issue of embodying co-benefits in monetary valuation methods applied to building energy efficiency projects is tackled on two sides. On one side, in section 5.6 it is proposed to include co-benefits in the traditional global-cost formula, in the framework of the well-established cost-optimal methodology. Possible effects of this inclusion were tested by applying literature-based benefits' monetization options related to the retrofit of an Italian Reference Hotel (see in Chapter 3). On the other side, in section 5.7 the question of how to monetize co-benefits was addressed directly. Among the long list of possible co-benefits, comfort was selected for the combined application of economic and engineering techniques devoted to monetizing non-market goods. Once again, these techniques were specifically applied to the Italian Reference Hotel case study.

5.6 Proposal of a global cost-benefit formula for cost-optimal analyses

First proposals of incorporating co-benefits in the well-established cost-optimal methodology can be found in (Gvozdenović et al. 2014) and (Becchio, Corgnati, et al. 2015). Gvozdenović et al. included productivity increase and sick leave reduction as "additional gains" in the Life Cycle Costs of an office building and proposed more market-oriented benefits (e.g. higher renting value, higher rest value) to be included in future studies (Gvozdenović et al. 2014). Becchio et al. identified possible co-benefits in view of amending the current global cost formula and they tested the effect of incentives in the cost-optimal analysis applied to the retrofit of a residential building (Becchio, Corgnati, et al. 2015) .

The present thesis collects these suggestions and focuses its attention on the inclusion in the global cost formula of co-benefits appreciated by private investors (financial perspective), by proposing a *global cost-benefit* formula. Specifically, the specific focus is on hotel businesses. The Italian Reference Hotel presented in section 4.3.2 was the baseline building to which a selection of envelope-related energy efficiency measures were applied.

Energy efficiency measures and packages of EEMs selected for the analysis are reported in section 5.6.1. Primary energy use and global cost calculation procedures are briefly recalled in sections 5.6.2 and 5.6.3 respectively. The obtained global costs were the terms of comparison for evaluating the effect of taking in co-benefits in the traditional global cost formula. Starting from these figures, the research process entailed the definition and the hypothetical quantification of co-benefits (described in section 5.6.4) and their inclusion in the financial calculations for each retrofit solution (see section 5.6.5). This research was object of a Conference paper co-authored by the PhD candidate and enclosed to the dissertation as Paper IX. In the followings, the paper's contents are recalled and further detailed.

5.6.1 Selected EEMs

Capital intensive EEMs for passive strategies of retrofit were prioritized as they are the first step to increase energy efficiency in the context of an overall building renovation and reinvestment. Specifically, envelope-related business-as-usual (BAU) and eco-friendly (ECO) EEMs described in Chapter 4, Table 4-13, Table 4-14 and Table 4-15, and BAU and ECO packages of EEMs from 1 to 10 as listed in Table 4-20 were the retrofit options envisaged for the Reference Hotel in this case study. To ease the reader, measures and packages are briefly recalled in Table 5-2 and Table 5-3 respectively.

Table 5-2: Energy Efficiency Measures applied to the Reference Hotel

Envelope component	Performance level	Strategy	EEM	Main Feature
External wall	1	BAU	E1.1	U = 0,28 W/(m^{2}K)
		ECO	E1.1eco	U = 0,30 W/(m^{2}K)
	2	BAU	E1.2	U = 0,24 W/(m^{2}K)
		ECO	E1.2eco	U = 0,24 W/(m^{2}K)
Ground floor	1	BAU	E2.1	U = 0,28 W/(m^{2}K)
		ECO	E2.1eco	U = 0,28 W/(m^{2}K)
	2	BAU	E1.2	U = 0,24 W/(m^{2}K)
		ECO	E1.2eco	U = 0,24 W/(m^{2}K)
Roof	1	BAU	E3.1	U = 0,23 W/(m^{2}K)
		ECO	E3.1eco	U = 0,24 W/(m^{2}K)
	2	BAU	E3.2	U = 0,23 W/(m^{2}K)
		ECO	E3.2eco	U = 0,24 W/(m^{2}K)
Windows/ doors	1	BAU	E4.1	U = 1,76 W/(m^{2}K)
		ECO	E4.1eco	U = 1,79 W/(m^{2}K)
	2	BAU	E4.2	U = 1,25 W/(m^{2}K)
		ECO	E4.2eco	U = 1,28 W/(m^{2}K)
Shadings	1	-	E5.1	overhangs
	2	-	E5.2	automated blinds

Table 5-3: Packages of EEMs applied to the Reference Hotel

Packages	EEMs included
PE1/PE1eco	E1.1(eco) + E2.1(eco) + E3.1(eco)
PE2/PE2eco	E1.2(eco) + E2.2(eco) + E3.2(eco)
PE3/PE3eco	E4.1(eco) + E5.1
PE4/PE4eco	E4.2(eco) + E5.1
PE5/E5eco	E1.1(eco) + E2.1(eco) + E3.1(eco) + E4.1(eco)
PE6/PE6eco	E1.2(eco) + E2.2(eco) + E3.2(eco) + E4.2(eco)
PE7/PE7eco	E1.1(eco) + E2.1(eco) + E3.1(eco) + E5.1
PE8/PE8eco	E1.2(eco) + E2.2(eco) + E3.2(eco) + E5.1
PE9/PE9eco	E1.1(eco) + E2.1(eco) + E3.1(eco) + E4.1(eco) + E5.1
PE10/PE10eco	E1.2(eco) + E2.2(eco) + E3.2(eco) + E4.2(eco) + E5.1

5.6.2 Primary energy use

The energy use of each model implementing EEMs and packages of EEMs were assessed through Energy Plus simulations and they were converted into primary energy by applying the Italian conversion factors (Ministero dello Sviluppo

Economico 2015b). In contrast with the energy analysis performed in chapter 4, section 4.3.7, in this application only primary energy was object of the energy analysis investigation and all end-uses were included (also equipment) in the calculation of the primary energy index. While in section 4.3.7 the goal was to compare the models' performance to specific minimum requirements, in this study the only objective was to calculate the primary energy use.

5.6.3 Global cost

The traditional global cost formula described in chapter 4, section 4.3.8, was applied to derive the global costs of EEMs and packages. However, as in this application maintenance costs and replacement costs remained constant in all retrofit options, these items were excluded from the calculation. Therefore, the extended formulation of the global cost formula applied to this study is elicited as follows:

$$C_G\,(\tau) = C_I\, + \sum\nolimits_j \left(\sum_{i=1}^{\tau} \left(C_e \times R_d(i) \right) - V_{f,\tau}(j) \right) \tag{5-1}$$

where,

- τ is the calculation period, here assumed equal to 20 years;
- C_I is the initial investment cost calculated as in section 4.3.8;
- C_e is the energy cost, calculated as in section 4.3.8;
- $R_d(i)$ in the discount rate for the year i, calculated as 4.3.8 and based on a real discount rate R_R of 4%;
- $V_{f,\tau}(j)$ is the final value of component j at the end of the calculation period

5.6.4 Co-benefits selection and monetization

As a preliminary step in view of a smooth implementation in the global cost formula, the co-benefits listed in Table 5-1 were grouped in initial, annual and final value benefits. This classification follows the same rationale proposed for costs by EU Regulation and guidelines. Figure 5-2 schematizes the proposed approach to benefits and costs classification for their inclusion in the *global cost-benefit* formula.

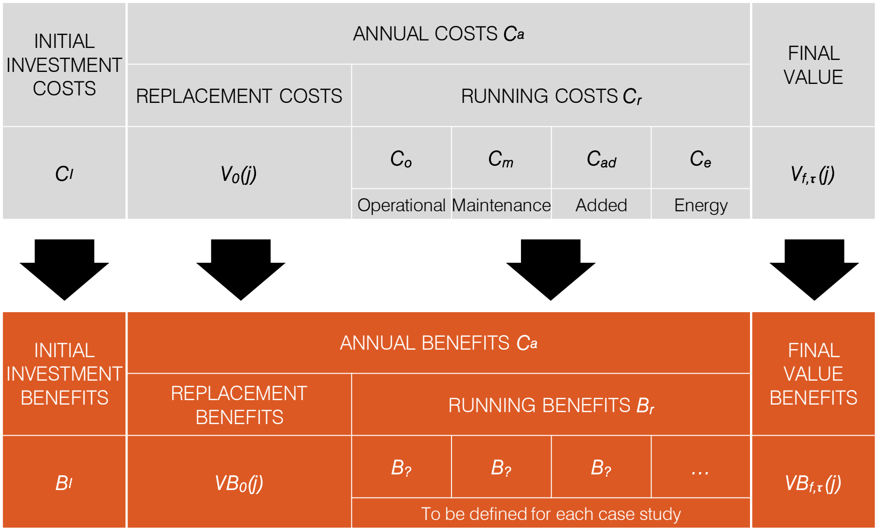


Figure 5-2: Initial, annual and final costs and benefits to be included in the global cost-benefit formula.

Then, first step for the inclusion of co-benefits is the selection of the case-specific items. Indeed, based on the building object of investigation, not all the proposed benefits may be interesting for the investor. In this thesis, the Italian Reference Hotel presented in section was taken as case study, therefore only co-benefits that may be interesting from a hotelier's standpoint were investigated. Additionally, replacement benefits were not considered in this application, as replacement costs were omitted from the global cost calculation (see section 5.6.3).

Once interesting co-benefits are identified, the next phase inevitably requires to monetize them. Being the monetization of co-benefits a currently pending big challenge, too much context-dependent to be summarized in exact figures, in this application different options of monetization for each co-benefit were proposed, based on literature. The selected co-benefits and their monetization options are listed, briefly justified and explained in the followings.

Initial benefits

- **Incentives** (i.e. subsidies in Table 5-1). As put forward by Becchio et al. (Becchio, Corgnati, et al. 2015), the inclusion of incentives in the cost-optimal analysis of specific buildings can play an important role in investors' decision making process. Here a null and two positive amount of incentives are considered, based on Italian dispositions (Agenzia delle Entrate 2016). Benefits are quantified as a percentage of the initial investment costs and they are accounted as a negative value in the revised cost-optimal formula.

Annual benefits (running benefits)

- **Reduced sick leave** (i.e. "reduced morbidity" in Table 5-1). Academic literature reveals a strong link between indoor air quality and Sick Building Syndrome (Hodgson 2011). This impact can be quantified by relating the economic value of a day of sick leave and the building ventilation rate, as proposed by (Fisk et al. 2003). In the present study EEMs do not modify the ventilation rate, therefore sick leave is assumed as constant and excluded from benefits calculation.
- **Improved Productivity** (see Table 5-1). It has been widely verified that indoor environmental quality (IEQ) affects employees' productivity. As shown by Seinre et al. (Seinre et al. 2014), productivity has a link with indoor air temperature and ventilation rates. Being ventilation constant among the considered retrofit options, in this work only the effect of indoor air temperature was considered. The equation statistically determined by Seppänen et al. (Seppänen et al. 2006) was used to define the variation in productivity (P). The obtained variation was related to the average hourly salary of an Italian employee (Salary = 16.83€/h), derived from the Italian institute for statistics (Istat). Only thermal zones dedicated to employees' work (reception and office) were considered. Depending on indoor air temperature, productivity variation may be a positive (i.e. a cost) or a negative value (i.e. a benefit) in the global cost-benefit formula.
- **Increased Service Price** (to be considered as "increased asset value" as mentioned in Table 5-1). In hotel businesses, there are two main documented drivers justifying an increase in service price (sp) that is acceptable for guests:
    - **Effects of a green attitude.** Several studies investigated the link between green hotels costumers' Willingness to Pay (WTP) and their level of environmental concerns. While some analyses identified a premium for booking a standard room in a green hotel (Kuminoff et al. 2010), others did not agree with this correlation (Manaktola & Jauhari 2007). The present study takes into account both points of view by introducing null, medium and high market appreciation of the green services. The monetization of medium and high service price increase used in this study were derived from the findings of the investigation performed by Kang et al. (Kang et al. 2012). In this paper, the authors

surveyed guests' WTP extra for green initiatives in hotels: the most frequent WTP answers were taken as numerical references in this thesis. When speaking of market appreciation of green initiatives, it must be specified that in the context of the hospitality sector promoting a green image in strongly linked to green certifications. As highlighted in section 3 of this thesis, hotel-related green certifications typically consider energy efficiency as one evaluation criteria of many and with no limit value to comply with. Therefore, the link between the high performing retrofit solutions and green certification is not obvious. On the other hand, attention is paid to the use of eco-friendly materials. The use of eco-friendly products for retrofit interventions may strengthen the link between the hotel retrofit and the market appreciation for a green hotel.

- o **Effects of comfort.** The effect of comfort in guestrooms on guests' WTP in green hotels was questioned as well. It is recognized that service quality is the main determinant of consumer satisfaction (Qi et al. 2017), while "non-essential attributes" such as commitment to sustainability deliver secondary benefits (Gao & Mattila 2014). On the other hand, monitoring studies proved that, given the same comfort level, occupants' of green buildings tend to complain less about IEQ than occupants of standard building (Newsham et al. 2012). Rahman and Reynolds (Rahman & Reynolds 2016) identified this behavior in green hotels as "willingness to sacrifice", which leads guests to accept lower service quality for higher rates. In the present case study, all retrofit measures did not improve guests' comfort conditions, constantly within EN15251 Comfort Category III (10%<PPD≤15%). Following the "willingness to sacrifice" theory, the effect of low comfort level was not considered in the monetization of service price. The Istat data about the average yearly profit of a small size Italian hotel (Profit = 387 k€/y) was used as starting value, to which the null/increased WTP percentage was applied. The extra profit is accounted as negative value in the global cost-benefit formula.

Final value benefits

- **Increased Market Value** (i.e. "Increased asset value" in Table 5-1). Market appreciation of energy efficient buildings has been confirmed by many studies. Most of the evidences are related to the effect of green certification on the real-estate market (Miller et al. 2008; Chegut et al. 2014). The effect of retrofit actions on the market value of existing "unlabelled" buildings was studied by Popescu et al. (Popescu et al. 2012). Based on the quoted references, three options of added value (MV) – low, medium and high - were considered and applied to the final value $V_{f,\tau}$(j). The value increase is added to the original $V_{f,\tau}$ (j) in global cost-benefit formula.

In Table 5-4 the described co-benefits are listed and coupled with their monetization formulas and options, with the corresponding references.

Table 5-4: Co-benefits in the global cost-benefit formula and their monetization options

Benefits			**Equation**	**Monetization options**			
Cat.	**Subcategory**			**Null (0)**	**Low (L)**	**Medium (M)**	**High (H)**
Initial	Incentives	B_I	$B_I = I \cdot C_I$	I_0= 0%	-	I_M= 36% [a]	I_H= 65% [a]
Running	Productivity variation	B_P	$P = 0,1647524 \cdot T - 0,0058274 \cdot T^2 + 0,00000623 \cdot T^3 - 0,4685328$ $B_P = P$ [b] $\cdot$Salary [c]				
	Increased service price	B_{sp}	$B_{sp} = sp$[d] $\cdot$Profit [c]	sp_0= 0%	-	sp_M= 5% [d]	sp_H= 10% [d]
Final value	Increased Market Value	$V_{MV,\tau}$ (j)	$V_{MV,\tau}(j) = V_{f,\tau}(j) \cdot MV$	-	MV_L= 3% [e]	MV_M= 9% [f]	MV_H= 15% [g]

[a] (Agenzia delle Entrate 2016)
[b] (Seppänen et al. 2006)
[c] http://dati.istat.it/
[d] (Kang et al. 2012)
[e] (Popescu et al. 2012)
[f] (Miller et al. 2008)
[g] (Chegut et al. 2014)

5.6.5 Including co-benefits in the global cost formula

The inclusion of the co-benefits listed above in the traditional global cost formula resulted in a revised *global cost-benefit* formula (CB_G), shown in equation (5-2):

$$CB_G(\tau) = (C_I - B_I) + \sum_j \left(\sum_{i=1}^{\tau} \left((C_e + B_P - B_{sp}) \times R_d(i) \right) + (V_n - VB_n) - \left(V_{f,\tau}(j) - V_{MV,\tau}(j) \right) \right) \quad (5\text{-}2)$$

Aimed at providing insights on the potential of each co-benefits category in modifying the global cost for the proposed interventions, scenarios combining different benefits monetization options were created. However, not all scenarios were applied to all retrofit options: monetization option were differentiated based on the retrofit approach (BAU or ECO). While null, medium and high investment benefits were applied to all EEMs and Packages for both the approaches, co-benefits related to the market appreciation of the retrofitted good were different between BAU and ECO solutions. Since evidences of higher market values are related to the effect of energy certification, the hypothesis of medium and high increased MV were applied only to ECO EEMs and packages of EEMs. A low market value increase was applied to BAU retrofit options only. The same principle applies for the application of service price benefits. As increased guests' WTP depends on the green image of a hotel and green image is closely linked to green certification, medium and high increases in service price were considered only in models implementing ECO EEMs and packages of EEMs. Coming to productivity co-benefits, their monetary value is function of the indoor thermal conditions and therefore independent from the retrofit approach chosen. The implemented benefits scenarios are presented in Table 5-5.

Table 5-5. Monetization options included in different global-cost benefits analysis scenarios

Scenario	Monetization options	Applied to
00L	$I_0 + P + sp_0 + MV_L$	BAU EEMs and Packages of EEMs
M0L	$I_M + P + sp_0 + MV_L$	
H0L	$I_H + P + sp_0 + MV_L$	
00M	$I_0 + P + sp_0 + MV_M$	ECO EEMs and Packages of EEMs
00H	$I_0 + P + sp_0 + MV_M$	
0MM	$I_0 + P + sp_M + MV_M$	
0HH	$I_0 + P + sp_H + MV_H$	
MMM	$I_M + P + sp_M + MV_M$	
MHH	$I_M + P + sp_H + MV_H$	
HMM	$I_H + P + sp_M + MV_M$	
HHH	$I_H + P + sp_H + MV_H$	

5.6.6 Financial analysis

As mentioned, cost-benefit analysis scenarios applied to BAU retrofit options were different from cost-benefit analysis scenarios applied to ECO retrofit options. Figure 5-3 displays the resulting *global cost-benefits* for the scenarios involving business-as-usual measures; Figure 5-4 refers to eco-friendly measures. In both figures, the contribution of each specific present values in the resulting *global cost-benefits* is displayed. These histograms enable the evaluation of the role of each co-benefit in modifying the global cost of a retrofit intervention.

The first remarks deal with the effect of productivity (B_P), variable included in all scenarios. As a function of indoor air temperature, B_P reduces the global cost only in case the indoor temperature of the retrofit option is most favorable for employees' productivity than indoor temperature of the RH. This is not the case of the present study, where the increased thermal performance of the envelope caused overheating and therefore reduced workers' productivity, turning a potential co-benefit into a co-cost.

The presence of incentives obviously reduced the financial burden of the retrofit options. Nonetheless, their contribution to reduce the global cost is rather small in comparison with other benefits and in relation to the specific costs considered in this study (investment and energy costs). In all packages, the investment benefits always represent less than 10% of the sum of the actualized energy and investment costs.

Starting from these remarks valid for all the considered retrofit solutions, Figure 5-3 highlights that for business-as-usual measures and packages, nor medium or high incentives, nor low market appreciation of the retrofitted good (i.e. a low market value increase), nor the combination of both, were enough to reduce the global cost-benefits below the global cost of the Reference Hotel in its original configuration.

Figure 5-4, instead, reveals at a glance the co-benefit having the deepest impact on the financial convenience of a retrofit measure: increased service price. Including service price benefits in the global cost-benefit formula led to a reduction in global cost of 155€ for medium appreciation (+5% WTP), of 309€ for high appreciation (+10% WTP) for all the ECO retrofit measures. Taking into account medium or high increase in service price makes almost any retrofit option more profitable than the baseline scenario. For eco-measures hypothesis of medium and high increase of the market value of the retrofitted good were tested. These co-benefits were of course higher than their corresponding items in BAU options, but in relative terms the market value increase always represent around 1% of the investment and energy costs of the ECO retrofit solutions.

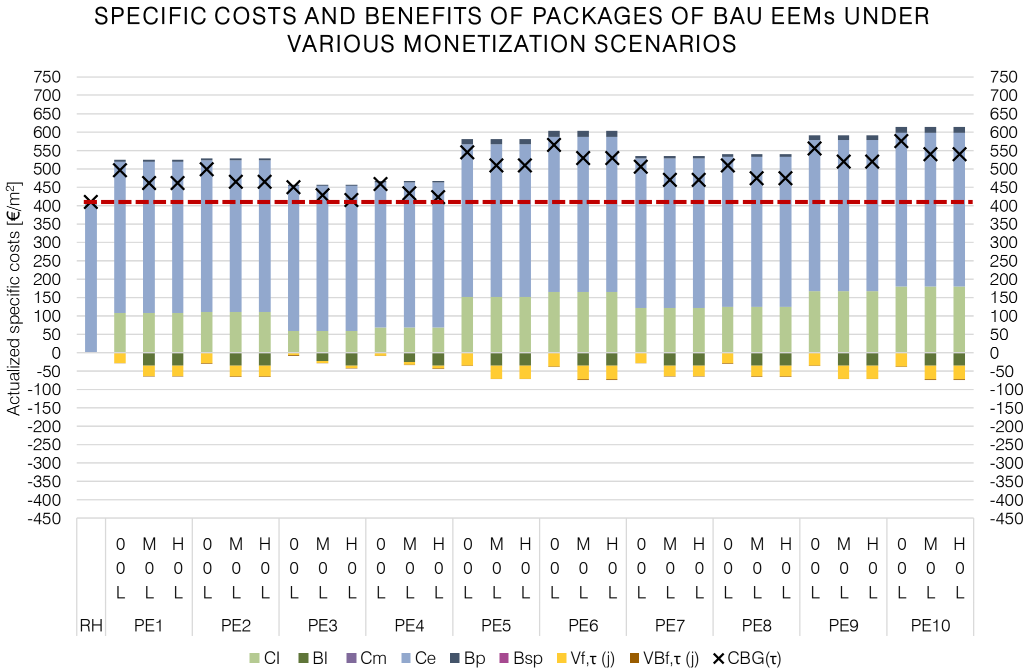


Figure 5-3: Specific present values of costs and benefits of BAU EEMs and packages of EEMs under various monetization scenarios

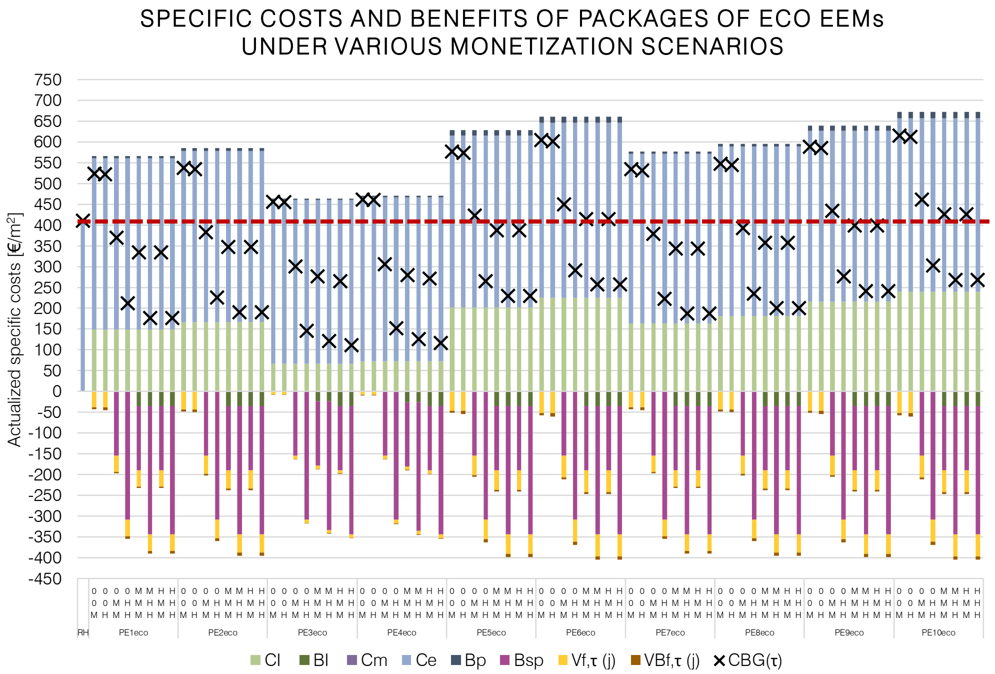


Figure 5-4: Specific present values of costs and benefits of ECO EEMs and packages of EEMs under various monetization scenarios

5.6.7 Cost-optimal graph

To study how co-benefits can modify the cost-optimal level of energy performance for the RH, for each EEM and package the global costs and the global-cost benefits for all monetization scenarios were plotted versus the corresponding primary energy use. Figure 5-5 reports the cost-optimal graphs for the BAU retrofit options, Figure 5-6 for the ECO ones.

As elicited above, the co-benefits monetization option investigated for BAU solutions did not make the global cost-benefit lower than the global cost of the RH, meaning that the cost-optimal level of energy performance in still represented by the primary energy use of the Reference Hotel in its original configuration, equal to 335 kWh/(m^2·y) (see Figure 5-5). Nonetheless, the combination of high incentives and low market appreciation (scenario H0L) is able to "flatten" the cost-optimal curve so that the most energy efficient options become, in terms of CB_G, as convenient as keeping the RH in its initial conditions, i.e. to widen the cost-optimal energy performance range (from 335 to 318 kWh/(m^2·y)). However, from the investors point of view, considering all the practical inconveniences that a renovation process entails, not even high public incentives can play the key role in modifying the profitability of a project toward energy efficiency.

In Figure 5-6, the leading role of increased service price (B_{sp}) in reducing the global costs of the intervention is evident. However, in terms of cost-optimal level of energy performance, figures remain almost unvaried. In the scattered plot, the cost-optimal solution for scenarios with Medium and High service price and market values increases is E3.2eco, which foresees roof insulation and has low impact on the overall building energy consumption, with a primary energy use equal to 334 kWh/(m^2·y). As noticed for Figure 5-5, medium and high incentives contribute to flatten the curves, therefore widening the cost-optimal range till 318 kWh/(m^2·y).

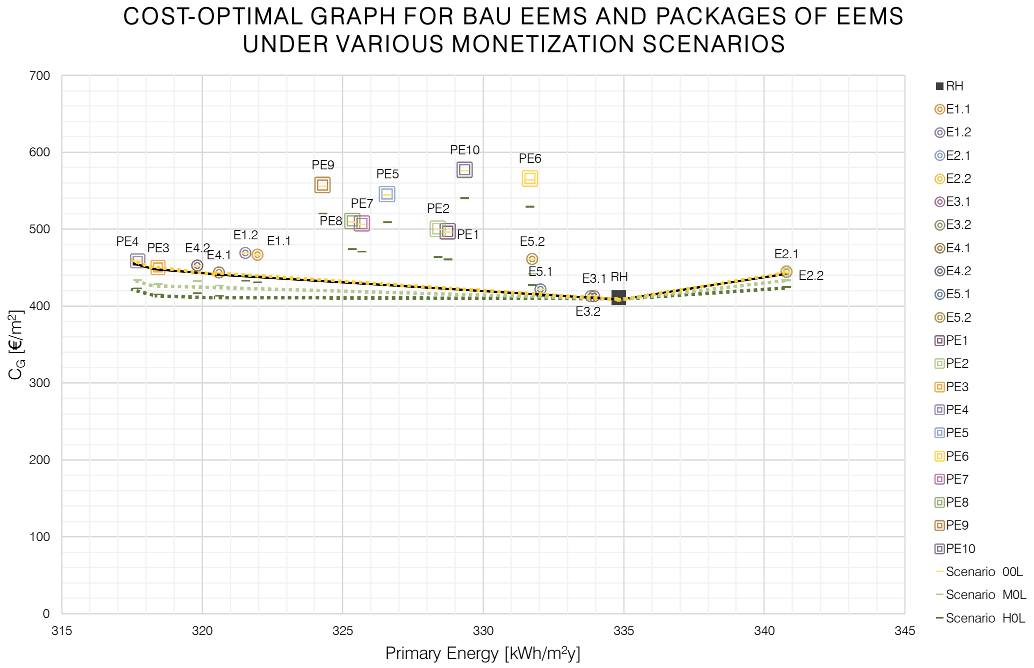


Figure 5-5: Global cost-benefit vs. primary energy for BAU EEMs and packages of EEMs

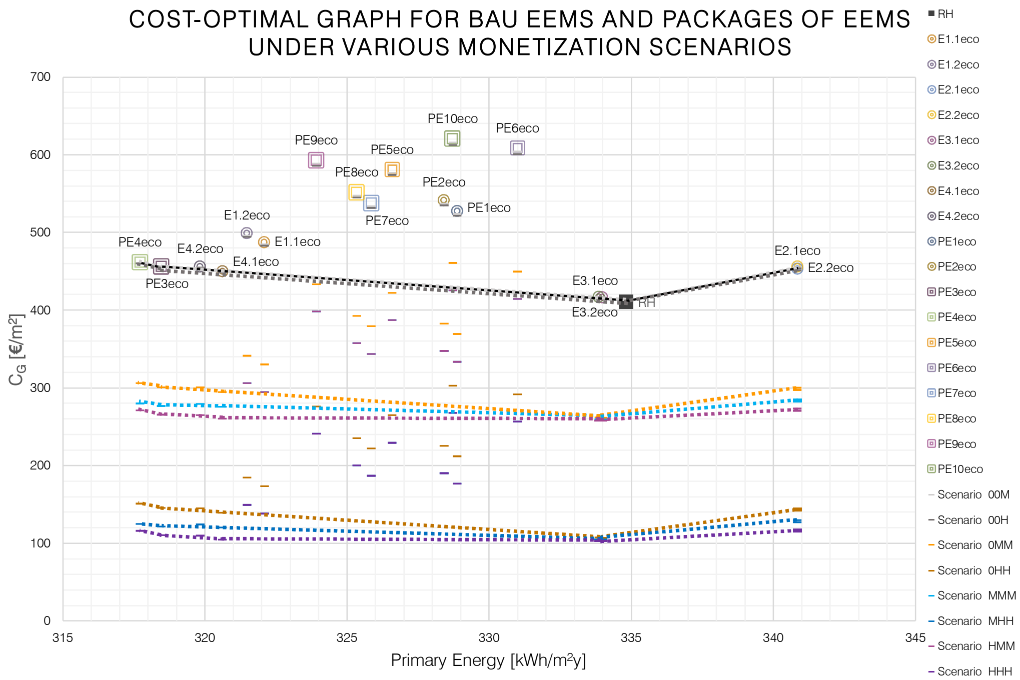


Figure 5-6: Global cost-benefit vs. primary energy for ECO EEMs and packages of EEMs

5.6.8 Discussion

Aim of the present application was to address the problem of adding extra benefits to the traditional global-cost methodology intended as a decision-making tool for investors at an early design stage. In general terms, the inclusion of co-benefits in the cost-optimal methodology proved to have a great potential in modifying investors' perception about the convenience of a retrofit intervention. The peculiarity of this case study application revealed that benefits related to an increase in service price have the biggest impact on global costs. The leading role of service price in modifying the profitability of an energy efficiency intervention justify the importance given by hoteliers to green labels. Indeed, studies have proved that guests are willing to pay more for staying in green structures, which are often labelled through green certifications.

Despite their positive impact on global cost, in this application co-benefits were not able to drive the cost-optimal level of energy performance towards lower values. In this regard, it must be noted that the envisaged retrofit options only influenced the building energy uses for climatization, while in the Reference Hotel equipment and lighting are responsible for 56% of the overall primary energy use (see chapter 4, Figure 4-8). Nonetheless, eco-friendly measures resulted as more convenient due to a higher co-benefit potential. If considering the energy assessment of these retrofit options from a Life Cycle perspective, the embodied energy of construction materials could have a strong impact in lowering the cost-optimal energy performance level. In this regard, findings of Giordano et al. should be recalled (Giordano et al. 2017). Through their analysis, the authors demonstrated that the incidence of embodied energy of a high performing office building accounts, for some design options, 50% of the whole building primary energy demand (i.e. operational energy + embodied energy).

Finally, the outcomes of this analysis build upon literature-based hypotheses and therefore cannot be taken as realistic quantitative references. Nonetheless, the analysis contributed to highlight that the positive effects of investments in energy efficiency are a fact. In addition, the study pointed out that occupants' health and well-being have an important role, not just from an ethical point of view, but also in the financial performance of a building.

5.7 A proposal for monetizing comfort

The inclusion of co-benefits in the appraisal discipline requires valuation methodologies for energy efficiency investment projects to go beyond the traditional engineering approach as a trade-off between accountable short-term costs and long-term benefits. Indeed, despite co-benefits quantification is complex and context-dependent, assigning a monetary value to co-benefits is the only effective way to include them in the decision process for investments in energy efficiency. To this purpose, researchers exploited economic valuation techniques (Popescu et al. 2012; Christersson et al. 2015; Park et al. 2013; Becchio et al. 2017) and proposed potential concrete indicators for their monetization (Ürge-Vorsatz et al. 2009).

When browsing Table 5-1, it can be noticed that Indoor Environmental Quality (IEQ) impacts the occurrence of co-benefits from many sides, as it includes acoustic, visual, thermal and Indoor Air Quality parameters (CEN 2007b). In this view, health co-benefits, comfort co-benefits and productivity co-benefits can be all ascribed to the IEQ level of the building under evaluation.

In past years, a branch of studies focused on assessing the role of Indoor Environmental Quality on occupants' health and productivity. Milton et al. (Milton et al. 2000) and Fisk et al. (Fisk et al. 2003) found consistent association between workers' sick leave with low ventilations rates through survey data and simulation results respectively. Seppanen et. al, based on literature review, proposed functions to assess the link between temperature, ventilation rates and productivity in offices (Seppänen et al. 2006). Haverinen-Shaughnessy et al. (Haverinen-Shaughnessy et al. 2015) and Toyinbo et al. (Toyinbo et al. 2016) focused on the influences of IEQ on students' learning outcomes. Vieira et al. (Vieira et al. 2016) revealed a link between the increased risk of symptomatologic complaints and the exposure to poor indoor environmental quality conditions in intensive care units. Based on these findings, the role of IEQ on sick leave and productivity can be valuated, as proposed for instance by Seinre et al. (Seinre et al. 2014) and Buso et al. (Buso et al. 2016).

Conversely, the effect of indoor conditions from the users' wellbeing perspective (i.e. comfort) was poorly investigated so far. Valuing comfort in itself is one of the most difficult areas of economic evaluation of energy efficiency actions, because of the inner subjectivity of comfort perception. The scientific approach to the evaluation of comfort has evolved over years as an investigation of physiological and psychological and sociological factors, in particular in the field of thermal comfort. The well-known Fanger's theory (Fanger 1970) based on the evaluation of thermal neutrality between the occupant and his surroundings, was complemented by the adaptive comfort theory proposed by de Dear and Brager in 1998 (de Dear & Brager 1998), who proved that occupants' level of adaptation and expectation is strongly related to outdoor climatic conditions as well. Recently, further theoretical developments suggested that occupants' motivation can play an ever greater role in occupants' comfort preferences (D'Oca et al. 2016).

Consequently, placing an economic value on the improvement in comfort is a topic tackled by very few researchers. Clinch and Healy (Clinch & Healy 2003) valued post-retrofit increased comfort levels in dwellings by using the proportion of energy savings forgone as a proxy for the value that households placed on comfort improvements. For instance, if post-retrofit actual energy savings amounted to 60% of the potential energy savings predicted through calculations, the remaining 40% of forgone savings was assumed to equal households' implicit willingness to pay to increase thermal comfort in their dwellings. Fang et al. (Fang et al. 2012) proposed a method that monetize comfort levels based on pre- and post-retrofit conditions. the Annualized Energy Related Cost (AERC) was calculated for several retrofit options of a reference residential building and plotted versus the comfort level, expressed in Fanger's indicators PMV and PPD. The difference in AERC between pre- and post-retrofit with the same comfort level (obtained thanks to a comfort-stat control in the simulation tool) represented comfort monetization. The European Commission, in its guidelines for Cost-Benefit analysis for investment projects (Sartori et al. 2014), suggests two possible cases for the evaluation of comfort benefits, based on a counterfactual scenario: (1) the pre- and post-retrofit comfort levels are equal and the benefit is calculated as the energy savings obtained with the retrofit; (2) post-retrofit comfort level is higher than pre- and benefits are equal to the difference between the energy cost that pre-retrofit building would have had to reach the post-retrofit (higher) comfort level and the post-retrofit energy cost. Common feature of these studies is that they monetize comfort as a function of the energy savings obtained by simulated energy efficiency measures in buildings. Moreover, the focus is on thermal comfort, mainly assessed through indoor temperature and Fanger's indicators, while psychological and sociological factors are not taken into account.

Despite the limited number of studies striving to monetize comfort co-benefits in energy efficiency interventions in buildings, comfort appears as a key element in all the relevant literature on the topic, both from public and private perspective. This statement builds upon solid findings from on-field studies: many post-retrofit surveys revealed that increased comfort is the main source of occupants' satisfaction (Hernández & Phillips 2015; Thomsen et al. 2016).

Within this framework, this piece of PhD dissertation aims at proposing a different approach to monetize comfort, taken from the economic valuation discipline, and at combining it with a more traditional engineering approach based on simulation results. The specific object of application is, once again, the hotel sector. Indeed, accommodation businesses build their success on the service quality offered, among which high indoor comfort levels are essential (Manaktola & Jauhari 2007). Qi et al. (Qi et al. 2017), in their analysis of IEQ complaints in 5-stars hotels in China, found a link between higher IEQ complaint rate and lower online rating of a hotel. Hence, it is licit to infer that in hotel buildings the monetization of comfort is an even more relevant issue to be faced, in view of influencing private investors.

The economic approach to the monetization of comfort co-benefits refers to the willingness to pay, typically used to directly valuate environmental goods. In section 5.7.1 an overview of the available willingness to pay techniques is presented, as a justification for the method selected for the application to the thesis case study. In section 5.7.2 the research question is elicited and contextualized: quantifying the willingness to pay (WTP) for improved indoor environmental quality (IEQ) in hotel rooms through the preferences revealed by potential guests. Because of the service-oriented nature of these commercial buildings, guests are expected to consider comfort as a factor influencing their willingness to pay. Moreover, the hotel sector has been object of many applications of the CVM aimed at evaluating guests' WTP for green practices (Manaktola & Jauhari 2007; Kuminoff et al. 2010; Kang et al. 2012), defined as an ancillary service. Findings of the present study can enable a comparison between guests' preferences for essential (comfort) and non-essential (green initiatives) attribute offered by a hotel.

The engineering approach to the monetization problem is presented in section 5.7.3. Based on simulation results for the Reference Hotel (see Section 4.3), the increase in energy bills that may be required to improve the RH comfort level without undergoing any retrofit measure was calculated.

The results presented in the following sections were also object of Paper X, co-authored by the PhD candidate and enclosed to this dissertation.

5.7.1 Valuation methods for environmental goods

The value of non-market goods can be obtained through to two different approaches to the problem: revealed and stated preferences. Revealed preferences (RP) techniques indirectly infer the value of non-market goods based on trends observed in the real market about goods related to the good object of evaluation. Stated preferences (SP) techniques, instead, derive information from direct questions to potential consumers of the good object of investigation, by asking their willingness to pay for it. SP techniques allow to value all those kinds of non-market good for which it may not be possible to observe the real worlds evidences required by the RP methods. Revealed preference approaches primarily allow us to measure the value of consumptive uses (use value), while stated preference approaches generally allow us to measure the value of non-consumptive uses (existence or option values). The characterizing features of the most used techniques for valuing environmental goods are shortly recalled in the following paragraphs, put together from the thorough explanations provided in manuals on the topic (Louviere et al. 2000; Carson & Czajkowski 2003; Bateman et al. 2004; Whitehead et al. 2011; Roscelli 2014).

Revealed preferences

Focusing on the valuation of environmental goods, as IEQ is, the most popular revealed preferences techniques are the travel costs and the hedonic price method.

The **Travel Costs method** is typically used to estimate economic use values associated with ecosystems or sites that are used for recreation (e.g. (Voke et al. 2013; Jones et al. 2017)). It measures time and travel cost expenses that people incur to visit a site, which represent the "price" of access to the site. The rationale behind the Travel Cost method is that as the price of access (i.e. the cost of travel) increases, the number of visits tend to fall. This method gives an *ex-post* quantification of the value of the good and it only refers to its use value. 2 methodologic variants are possible: the zonal and the individual approach. The zonal one, most used, bases the estimation upon the analysis of the number of visits in a defined time frame and considering visitors' origins. Individuals accessing the service are segmented into different zones and travel distances and hence travel cost for each zone is estimated. From these data it is possible to estimate the demand curve to show how demand varies with the cost of access, and by extension how demand may change should the currently fixed price increase or decrease. The individual variant refers to data collected from single visitors rather than the information derived at the aggregated level. Main sources of bias for this method are its total dependence on interviews' circumstances and the limited temporal frame of the surveys.

The **Hedonic Price method**'s funding assumption is that a market good be an aggregate of several features, which do not have individual prices. Therefore, the method exploits the prices of market goods to estimate the implicit prices of its single features. The function used to determine the market price of a good based on these attributes is the *hedonic price function.* This method is largely used to estimate the influence of externalities on buildings market values and the link between building attributes and their selling/renting prices (Rosen 1974). It allows measuring the extent of the single implicit price of each building feature on the final price using a multiple regression analysis. In this context, many studies in these years employed the hedonic method to investigate the impact of energy certifications/labels/performances on the price of residential and commercial buildings (Eichholtz et al. 2010; Park et al. 2013). Specific applications can be spotted in the context of hotels, where the price premium for green/eco-friendly lodging is typical object of analysis (Kuminoff et al. 2010). Major strengths of this method are its being market-based, the rigorous theoretical procedure and the effectiveness of its findings to the audience. On the other hand, this technique necessarily requires a real and transparent real estate market and its estimations can be falsified by unrealistic costumers' expectations.

Stated preferences

The family of stated preference (SP) methods can measure the total economic value by incorporating both non-use value and option value. This implies that SP can be used to value potential future or hypothetical (but realistic) goods and interventions. The main categories of State Preferences methods for environmental goods are the Contingent Valuation Methods (CVM) and the Choice Experiments (CE).

Contingent Valuation Methods (CVM) Conceived in 1947 (Ciriacy-Wantrup 1947), the CVM was first applied in the '60s (Davis 1963) and since then it found wide applicability in the field of environmental economics. (e.g. noise reduction (e.g. (Galilea & Ortúzar 2005), CO_2 emissions reduction (e.g. (Adaman et al. 2011)). Some studies specifically focused on the hotel sector, investigating guests' willingness to pay for staying in green hotels (e.g. (Kang et al. 2012)). CVM design steps are well established:

I. Formulation of the valuation problem;
II. Draft of additional questions (debriefing, attitudes and demographics);
III. Pre-test of the questionnaire.

In the valuation problem respondents are required to declare their maximum Willingness to Pay (WTP) or minimum Willingness to Accept (WTA) for changes in the quantity or quality of a good/service/policy. The array of most popular CVM methods are: open-ended, close-ended, iterative bidding game, payment card. Open-ended elicitations ask respondent their maximum WTP. Close-ended interrogations are based on the dichotomous choice approach and ask the respondent whether he would pay X to obtain the good or not. The iterative bidding game starts by querying individuals at some initial monetary value and keeps raising (or lowering) the value until the respondent declines (accepts) to pay. The final amount is interpreted as the respondent's WTP. With the payment card approach a number of possible WTP values are listed and the respondent is asked to pick the amount on the card that best represents his willingness to pay. The amount chosen by the respondent can be interpreted as the respondent's WTP. Several critics to CVM have been moved in literature. A major weakness identified is that the value attached to a non-market good is entirely hypothetical. For instance, a common phenomenon is the "warm-glow" effect, for which people enjoy saying that they would contribute to a good cause. Differences between real and hypothetical settings are referred to as ‘‘cheap talk", which researchers try to limit this by adding a direct explanation of this problem to their survey document. Another major potential cause of bias is related to how the willingness to pay question is asked. The framing of the WTP scenario is crucial, as it may lead respondent to feel it too complex or irrelevant to them (Saayman et al. 2016). Moreover, different elicitation methods can lead to different answers (Hess et al. 2010). Typically, open ended questions can lead to high non-response rate and, in general, to less reliable responses; close ended queries generally provide over-estimated WTP with respect to the open-ended form and provide less information to the analysists; in iterative bidding, respondents may be influenced by the starting values and succeeding bids proposed; payment card approach is exposed to biases relating to the range of the numbers used in the card and the location of the benchmarks. Finally, the intrinsic limitation of the CVM is that it only evaluates the good in its entirety. However, CVM approaches are still widely used and often provide an attractive method for collecting willingness to pay information in situations where interview duration or difficult fieldwork conditions are a consideration or when it is difficult to develop choice scenarios of the service or policy under consideration.

Choice experiments provide a more direct route to the valuation of the attributes of a good, and of marginal changes in these characteristics, rather than the value of the good as a whole. Respondents are asked to choose which mutually exclusive scenarios they prefer for a good. The (environmental) goods to be evaluated are described in terms of their attributes and of the levels and ranges these attributes can take. To provide meaningful results, a Choice Experiment requires a careful design, that involves the use of statistical design theory to construct choice scenarios which can yield parameter estimates that are not confounded by other factors.

The steps of a Choice experiment are:

I. Definition of the problem;
II. Development of a qualitative study (to identify alternatives, attributes and levels);
III. Design of the experiment;
IV. Generation of choice sets;
V. Construction of the survey instruments.

Choice modelling techniques can be classified into four categories, which reflect differences in theoretical assumptions, methods of analysis and experimental design procedures: Discrete choice or stated choice experiments; Contingent ranking; Contingent rating; paired comparisons. In *discrete choice experiments* (DCEs), respondents choose one alternative out of two or more alternatives on offer. Each respondent may be asked to repeat the choice exercise multiple times; with the levels of the attributes changing according to an experimental design. A *contingent ranking* exercise are more cognitive demanding for respondents, who must rank all of the alternative options on offer. In a *contingent rating* experiment, respondents are presented with one alternative at a time and are asked to rate each one separately (e.g. low preference - high preference). The degree of task complexity in contingent rating is even higher than contingent ranking or discrete choice experiments as respondents have to place a value on each alternative (Louviere et al. 2000). Finally, *pairwise comparison* exercises ask respondents to choose their preferred alternative from a set of two choices and to indicate the strength of their preference in a numeric or semantic scale, in a sort of combination of a discrete choice experiment and rating exercise. In terms of practical application, discrete choice experiment method is considered as the approach that more closely mirrors the respondents' real-life choice experiences (Louviere et al. 2000). In view of this fact, academic literature converged around DCE to value environmental good marginal attributes (Carson & Czajkowski 2003). Choice experiments drastically reduces the sources of bias highlighted for CVM, they guarantee higher stability of respondents' preferences and they are able to estimate several attribute values simultaneously. However, debates are ongoing about various DCE reliability and validity aspects among SP practitioners (e.g. (Que et al. 2017; Rakotonarivo et al. 2017)). Additionally, lack of time and budget are often obstacles for the implementation of these experiments, as DCE requires a complex and long design phase, as well as specialized analysis tools (Accent 2010).

In Figure 5-7 the main valuation methods applied to environmental goods described above are schematized.

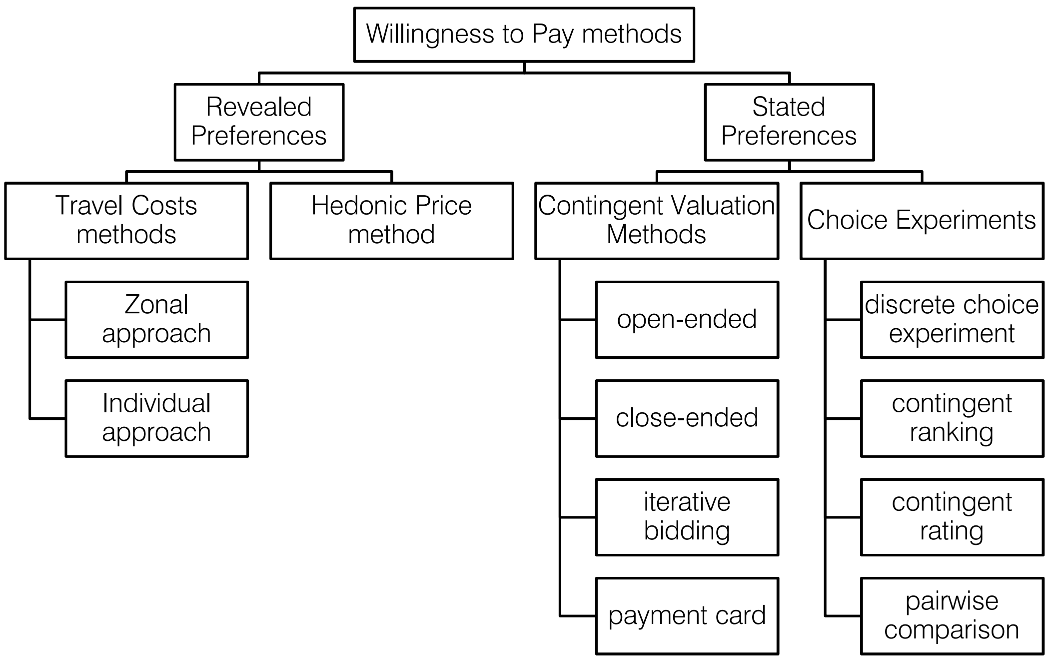


Figure 5-7:Most popular Willingness to Pay methods for environmental goods

5.7.2 CVM to monetize comfort benefits in hotel guestrooms

Given the panorama of valuation methods for environmental goods, Stated Preferences are considered the most suitable approach to valuate Indoor Environmental Quality in hotel rooms, as they can measure its total economic value in a direct way. Specifically, the application of the Contingent Valuation Method was preferred. Indeed, CVM has been widely exploited in academic literature for valuing outdoor environmental parameters such as acoustic annoyance (Galilea & Ortúzar 2005) and air quality (Carlsson & Johansson-Stenman 2000), paving the way for parallel investigation lines on indoor environmental parameters (unexplored so far). Additionally, CVM has been applied to the hotel sector by many studies, aiming at valuing guests' WTP for green practices (Manaktola & Jauhari 2007; Kang et al. 2012). The present case study combines the mentioned fields of application by investigating hotel guests' willingness to pay for excellent indoor environmental conditions in their rooms.

An on-line questionnaire was the selected survey method, as it ensures low costs, short elapsed time for receiving answers, wide geographic spread and lack of bias due to the interviewer's presence and attitude. Moreover, even if web-respondents do not represent the full sample of population, the target population for this research – travelers – mostly do. The main survey was launched in June 2016, when the questionnaire was mailed through a Google Forms link to 900 Italian citizens over-20. 30 days were allocated for its completion.

Building upon the theoretical background presented in section 5.7.1, the Contingent Valuation Method was here applied as follows:

I. **Formulation of the valuation problem**. After some background information aimed at pointing out the role of comfortable indoor environment in improving personal satisfaction and physical and psychological well-being, the issue of the extra operational costs for excellent comfort condition was presented. In hotels, an increase in room price was suggested as a solution to balance these extra-costs. Then, the core question was elicited as follows (translation from the original in Italian):

   "*Suppose that you are going to spend one night in a double room in a hotel located in Turin Centre at a tariff of 80 €/night. Suppose that the comfort conditions of the guestroom are not satisfactory with reference to air quality, temperature, noise and light. Assume that the payment of an additional amount will help to improve and maintain excellent comfort levels in this room. How much is the maximum additional amount (€/night) that you would be willing to pay in order to enjoy excellent comfort conditions in your room?*"

The starting room rate was set equal to 80€/night based on web research on June 2016 tariffs for a double room in hotels located in Turin center[16]. The framed scenario is very specific and close to respondents' personal experiences, both in terms of payment methods (increase in room rate) and proposed changes in the good (increase in comfort). As inferred by Carlsson and Johansson-Stenman (Carlsson & Johansson-Stenman 2000), issues that relate to individuals are less sensible to the "warm-glow" effect and allow respondents to behave as real consumers. Moreover, the easy understanding of the scenario minimizes the non-response risk and allows asking an open-ended question. Many advantages can be reaped by the analysists using the open-ended elicitation format: the question is simple and immediate, it does not affect respondents with anchoring values, it captures the maximum WTP for each respondent and it requires relatively straightforward statistical methods (Bateman et al. 2004).

II. **Draft of additional questions**. A bundle of questions forerun the valuation problem, performed to understand and individuate respondents' travel attitudes, frequency of and duration of trips, and type of preferred accommodation structure. A sub-section was specifically dedicated to investigating consumers' attention for any environmental policy undertaken by the hotels. Then, a second group of questions aimed at evaluating respondents' experiences in hotels related to comfort, referring to their acoustic, visual, thermal, and indoor air quality (IAQ) sensations in guestrooms and to any possible symptom of Sick Building Syndrome (SBS) (e.g. eye, nose or throat irritation, dry cough), due to indoor pollutants sources and low ventilation rates. A number of additional questions were asked about the annoyance source and about remedies adopted to reduce annoyance. The latter aimed at assessing respondents' attitude towards uncomfortable indoor conditions. After the valuation problem, demographic and socio-economic questions were placed, since these aspects could be more sensitive to some respondents (employment and incomes).

III. **Pre-test of the questionnaire**. A series of focus group interviews was carried out to develop and check different sections of the questionnaire and a pre-test of the questionnaire was mailed to 20 respondents before the final version was send out.

[16] Data source for market analysis: www.booking.com

In its final form, the online questionnaire consisted of four sections: I) consumers' attitude regarding accommodation, II) consumers' experience, III) payment scenario, IV) demographic and socio economic data. A copy of the questionnaire (English translation from the original in Italian) is enclosed in Paper X.

The so-structured questionnaire chiefly aimed at investigating the average and frequency distribution of respondents' WTP for increased comfort conditions in a hotel room. As a supplementary analysis, the descriptive statistics of responses were coupled with econometric estimations, which provided insights on the links between WTP and respondents' characteristics thanks to statistical analysis based on associations among variables. In view of the inclusion of the survey answers in econometric models, questions were translated into variables, as displayed in Table 5-6. These analyses therefore included the main factor (WTP) and 25 independent variables, which can be broadly categorized in socio-economic, travel attitudes, preferred accommodation, environmental attitudes and discomfort experiences in hotels. The socio-economic variables are meant to capture objective differences in individual characteristics, while variables on travel attitudes and accommodation explain the number of trips in the last year, the travel motive, the average expenditure per night for hotel room and the type of accommodation structure. The variables on environmental activity interest capture the subjective consumer propensities towards the environment issue. The last group of variables captures the consumers' experience of discomfort conditions (acoustic, visual, thermal and IAQ) in hotel rooms. As shown in Table 5-6, to each variable an alphanumeric code was assigned, coupled with codification values for its quantification in the econometric models.

Table 5-6: Description of the variables of the used functions for the econometric estimations

Variable	Description	Codification
	DEPENDENT VARIABLE	
WTP	Willingness to pay for improved indoor conditions in hotel rooms	In monetary terms (Euro)
	INDEPENDENT VARIABLES	
	SOCIO-ECONOMIC VARIABLES	
AGE	Respondent’s age	In years since birth
GEN	Respondent’s gender	GEN=0 for female and GEN=1 for male
INC	Respondent’s income level	Amount of monthly income
EDU	Respondent’s education level	Amount of school years
	TRAVEL ATTITUDES	
TRIPS	Number of trips in the last year	In numbers of trips
ATIME	Average time spent in travel	Amount of days spent in each trip
PRICE/NIGHT	Average expenditure for each night in hotel	Average room rate per night (Euro)
MOTIVE	The motive for travelling	0 if it is a business travel, 1 if it is a leisure travel
	PREFERRED ACCOMMODATION	
AIRBNB	Respondent usually books in Airbnb or similar	0 if the respondent doesn’t book; 1 if he usually does
B&B	Respondent usually books in Bed&Breakfasts	
RESIDENCE	Respondent usually books in residences	
HOSTEL	Respondent usually books in hostels	
1,2STARS	Respondent usually books in 1/2-stars hotels	
3STARS	Respondent usually books in 3-stars hotels	
4STARS	Respondent usually books in 4-stars hotels	
5STARS	Respondent usually books in 5-stars hotels	

ENVIRONMENTAL ACTIVITIES AND ATTITUDES		
ENVATTENTION	It investigates whether the respondent has ever paid attention to the environmental policy of a structure while choosing an accommodation	0 if the respondent never paid attention, if so the value is 1
ENVACCOMODATION	This variable explores the frequency of experiences in green accommodations	On a 5-points scale, 0 representing 'Never', 1 'Rarely', 2 'Sometimes', 3 'Often', and 4 'Very often'
ENVACTIVISM	A dichotomous variable that explains the personal involvement in pro-environmental activities	0 representing no interest and 1 full interest in environmental activity.
ENVATTITUDE	Factor loadings for considering the presence of an environmental policy as a key criterion in the choice of an accommodation	A scale between 0 and 1, 0 representing no interest and 1 full interest in selecting green accommodations
EXPERIENCES OF DISCOMFORT IN ACCOMMODATION STRUCTURE		
ACOUSTIC	Frequency of acoustic annoyance	The perception of the annoyance on a 5-points scale, 0 representing 'Never', 1 'Rarely', 2 'Sometimes', 3 'Often', and 4 'Very often'
VISUAL	Frequency of visual annoyance	
THERMAL	Frequency of thermal annoyance	
IAQ	Frequency of Indoor Air Quality annoyance	
SBS	Frequency of eye/nose/throat irritations in hotel rooms	

CVM results

In total, 273 questionnaires were returned (30% response rate), of which 224 questionnaires were considered valid (25% response rate). Based on literature (Anderson, James C. Gerbing 1988), the sample size was considered large enough and the collected observations were the basis for the descriptive and the econometric analysis.

The core of the descriptive analysis was the quantification of respondents' WTP. As reported above, interviewees were asked the additional amount per night they would pay for improving their comfort level in a guestroom. The obtained results are statistically described in Table 5-7. About 18% of respondents (N=40) stated a null additional WTP. Major cause for these zero-bids lied in the valuation scenario proposed in the questionnaire: the baseline room rate was 80 €/night, based on average prices for hotels in Turin center. This starting price was perceived too high by most of the zero-bids respondents, who stated that, for such a tariff, their comfort expectations should have been satisfied by default. However, the mean WTP for increased comfort conditions was higher than 10€/night and the modal value was 20 €/night when considering the positive WTP sample as well as the whole sample. In percentage terms, among the whole sample, an average 14% increase in the baseline room rate, quantified in 11,47€/night, was obtained as the marginal WTP *procapite*. By plotting the marginal WTP versus the cumulative frequency (F_c) of answers, a linear relation among the variables was detected (R^2=0,93), as shown in Figure 5-8. The total surplus generated by improvements in respondents' comfort condition could be estimated as the integral of the function between the minimum and maximum frequency.

Table 5-7: Willingness to Pay for the sample

	Mean [€]	**St. dev. [-]**	**Median [€]**	**Mode [€]**	**Zero-bids [%]**	**Min. [€]**	**Max. [€]**	**N. [-]**
WTP whole sample	11,47	8,104	10	20	17,9	0	40	224
Positive WTP	13,96	6,710	10	20	-	1	40	184

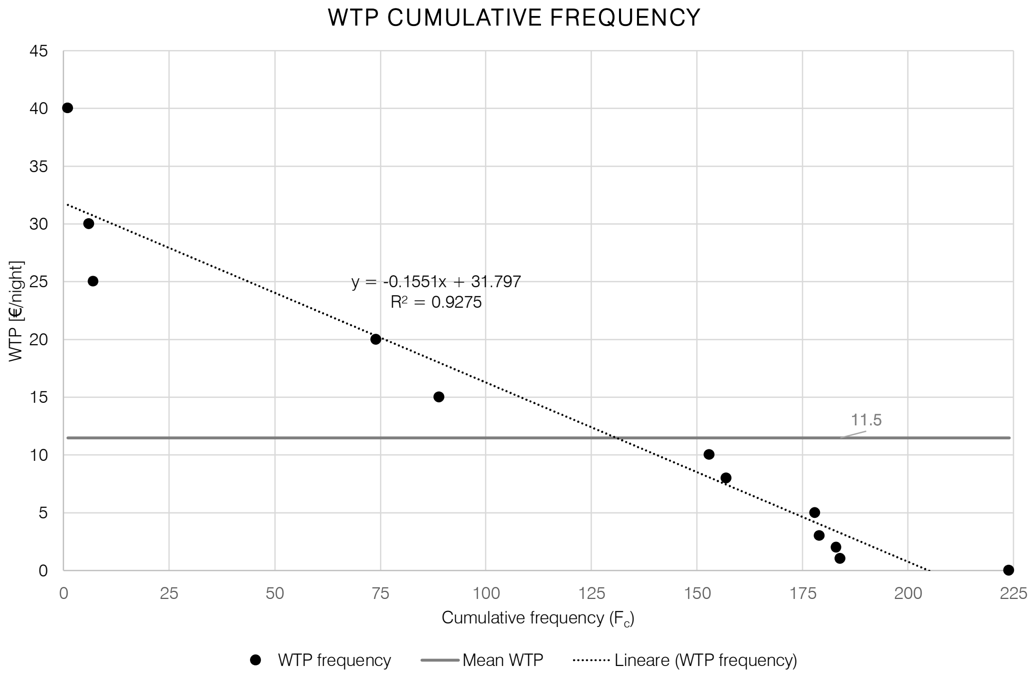


Figure 5-8: Cumulative frequency of Willingness to Pay

The econometric estimation models, instead, aimed at verifying the presence and at quantifying the influence of respondents' features on WTP. Hence, a multivariate analysis was the preferred statistical approach. Particularly, the study performed a linear multiple regression analysis and a binomial logistic one. The two WTP equations were obtained using SPSS 21[17].

First, the analysis included the dependent variable (WTP) and all independent variables (socio-economic, travel attitude, environment activities and attitudes, and perception of discomfort conditions). The WTP was translated into a dummy variable (i.e. null WTP=0; positive WTP=1), in order to include it in both analyses, keeping in mind that, unlike multiple linear regression, the binomial logistic one can only be used to predict a dichotomous dependent variable. Since nominal variables about discomfort conditions and environmental accommodation had more than two choices, they were also translated into dummy variables; to 'Never' option

[17] Software information available at: http://www.ibm.com/analytics/us/en/technology/spss/

the value of ‘0’ was assigned, while ‘Rarely’, ‘Sometimes’, ‘Often’, and ‘Very often’ choices were allotted the value ‘1’.

Then, the estimation models were refined by including in formulas only relevant variables, which were selected according to their significance in the full model. In order to test the significance of a variable, the *p*-value must be lower than the significance level defined a priori by the analysts. Typical significance level thresholds, selected for this analysis, are 0,1, 0,05 and 0,01. Therefore, only the variables showing *p*-values lower than 0,1 were included in the refined estimation models (Sproull 2002).

The results and predictive performances of the full and reduced regression models are shown in Table 5-8 and Table 5-9 respectively. The given coefficients of the estimation represent the dependence of the dependent variable (WTP) on its related independent variable, net of the other independent variables in the equation. The goodness-of-fit of the estimation models, i.e. how much variability the model is able to explain based on the initial data, is displayed in table by the R^2 coefficient, where 1 represent the perfect fit. Moreover, the *F*-test allows identifying the model that best fits the population from which data where sampled.

Table 5-8: Summary of multiple linear and logistic regression for the full model

	Multiple Linear Regression		**Binomial Logistic Regression**	
FULL MODEL				
***F*-value**	1,971		-	
***p*-value**	0,006*		0,005*	
R^2 | Nagelkerke R^2	0,098		0,310	
Variables	Coefficient	*p*-value	Coefficient	*p*-value
SOCIO-ECONOMIC VARIABLES				
AGE	-0,073	0,395	-0,034	0,208
GEN	-0,164	0,019**	1,038	0,023**
INC	-0,007	0,932	0,000	0,741
EDU	0,001	0,987	-0,017	0,822
TRAVEL ATTITUDE				
TRIPS	-0,154	0,050**	-0,114	0,044**
ATIME	-0,029	0,685	-0,011	0,843
PRICE/NIGHT	0,081	0,366	0,011	0,326
MOTIVE	0,043	0,574	-0,323	0,572
PREFERRED ACCOMMODATION				
AIRBNB	-0,021	0,772	0,089	0,859
B&B	-0,159	0,028**	1,109	0,023**
RESIDENCE	0,036	0,600	-0,146	0,837
HOSTEL	-0,006	0,934	0,017	0,927
1-2 STARS	-0,001	0,989	-0,351	0,668
3 STARS	-0,001	0,984	-0,055	0,902
4 STARS	0,062	0,450	-0,765	0,260
5 STARS	0,066	0,333	-19,147	0,999
ENVIRONMENTAL ACTIVITIES AND ATTITUDE				
ENVATTENTION	0,017	0,821	-0,131	0,817
ENVACCOMODATION	0,070	0,323	-0,374	0,388
ENVATTITUDE	0,035	0,634	-0,381	0,453
ENVACTIVISM	0,176	0,018**	-1,398	0,013**
EXPERIENCES OF DISCOMFORT				
ACOUSTIC	0,184	0,009*	-1,687	0,015**
IAQ	0,177	0,012**	-1,369	0,010**
THERMAL	-0,143	0,046**	1,712	0,067***
VISUAL	0,043	0,550	-0,298	0,586
SBS	-0,052	0,461	0,552	0,273

* Statistically Significant at 1%

** Statistically Significant at 5%

*** Statistically Significant at 10%

Table 5-9: Summary of multiple linear and logistic regression for the reduced model

	Multiple Linear Regression		Binomial Logistic Regression	
	REDUCED MODEL			
***F*-value**	5,625		-	
***p*-value**	0,000*		0,000*	
R^2 | Nagelkerke R^2	0,127		0,213	
Variables	Coefficient	*p*-value	Coefficient	*p*-value
	SOCIO-ECONOMIC VARIABLES			
GEN	-0,171	0,009*	1,109	0,006*
	TRAVEL ATTITUDE			
TRIP	-0,155	0,023**	-0,106	0,020**
PRICE/NIGHT	0,139	0,032**	0,014	0,045**
	ENVIRONMENTAL ACTIVITIES AND ATTITUDE			
ENVACTIVISM	0,144	0,032**	-0,891	0,063***
	EXPERIENCES OF DISCOMFORT			
ACOUSTIC	0,170	0,009*	-1,176	0,036**
IAQ	0,172	0,009*	-0,952	0,032**
THERMAL	-0,125	0,063***	-	-

* Statistically Significant at 1%

** Statistically Significant at 5%

*** Statistically Significant at 10%

Multiple linear regression. One way analysis of variance (ANOVA) in linear regression was performed to test the statistically sufficiency of the model. Since the *F*-value is equal to 1,971 and *p*-value to 0,006, the model fit is statistically sufficient. The R-square (R^2) in multiple regression analysis is quite low, 0,098. To test the variables significance in the full model, the *p*-value of each variable was considered. The resulted significant variables are GEN (gender, *p*-value=0,019), TRIP (trips number, *p*-value=0,050), B&B (B&B accommodation frequency, *p*-value=0,028), ENVACTIVISM (personal activism in environmental issue, *p*-value=0,018), ACOUSTIC (acoustic discomfort annoyance, *p*-value=0.009), IAQ (indoor air quality discomfort annoyance, *p*-value=0,012), THERMAL (thermal discomfort annoyance, *p*-value=0,046). The reduced multiple linear regression included in the analysis only the significant variables: GEN, TRIP, PRICE/NIGHT, ENVACTIVISM, ACOUSTIC, IAQ, THERMAL. Results changed in significance terms, reaching better performances. The model fit of the reduced model was better than the full model; the *F*-value was equal to 5,625, the R^2 to 0,127 and *p*-value less than 0,000.

Binomial Logistic Regression. The model fit was tested through the Nagelkerke R^2, that is a pseudo R-square, and the p-value. Indeed, logistic regression misses the equivalent R-square, used in linear regressions. The model fit is statistically sufficient with Nagelkerke R^2 equal to 0,310 and p-value to 0,005. The significant variables in the logistic full model are the same of the linear regression one, as shown in Table 5-8. In the reduced model, the significant variables were: GEN, TRIP, PRICE/NIGHT, ENVACTIVISM, ACOUSTIC, IAQ. In this case, the value of pseudo R^2 was lower than that of the full model (Nagelkerke R^2=0,213), but significance was higher (p-value<0,000).

Interestingly, the sign of the coefficients referring to dichotomous variables is reversed in the two models. In the linear regression model being male, the involvement environmental activities and previous experiences of acoustic and air quality discomfort contribute in raising the WTP. On the opposite, these features decrease the predicted WTP in the logistic regression model. Given two models that predict contradictory outcomes, the one yielding the better empirical interpretation of data must be chosen. By comparing the information emerging from the two regression analyses - R^2 (linear regression) and Nagelkerke R^2 (logistic regression) - the better-fit model is the logistic one where the independent variables predict more reliably the value of the dependent variable (WTP). Despite the opposite sign, according to both regression analyses the most significant independent variable is gender (GEN). Moreover, in both models the WTP seems to be strongly correlated (positively in linear model, negatively in logistic model) with ACOUSTIC and IAQ discomfort data.

However, when drawing these conclusions, the boundaries of the analysis must be recalled. Indeed, as a trial test in this interdisciplinary field, only Italian respondents' answers were analyzed to derive Willingness to Pay information. Findings of Wang and Huang, for instance, reveal the influence of hotel guests' homeland in energy use patterns and hotels' revenues (Wang & Huang 2013). On the same line, variations in terms of socioeconomic composition or travel attitudes of respondents could have led to different outcomes of the econometric analysis. Even the same respondents could have given different answers, if interviewed at a different time. Indeed, valuing comfort is a very delicate and subjective task. As occupants' comfort perception and energy related behaviors are the products of physical, contextual, physiological, psychological and social drivers (Fabi et al. 2012), any difference in the survey methods or participants (e.g. proposing the questionnaire in a different country or at a different time of the year) could have given different findings. In this framework, the insights offered by the present research are just the starting point for broader investigations, able to seize a more comprehensive range of drivers influencing guests' preferences.

5.7.3 The engineering approach to monetize comfort costs in hotel guestrooms

The engineering approach was here exploited to quantify comfort costs based on simulations. Specifically, object of the analysis was thermal comfort. The Reference Hotel Energy Plus model, described in section 4.3, was used as case study. Among factors influencing Indoor Environmental Quality, thermal comfort was selected as the focus of the engineering analysis because: a) according to the survey results, indoor thermal conditions were the most perceived causes of annoyance (91.5% of respondents); b) in the hypothesis of improving comfort conditions in an existing hotel, indoor temperature is the easiest parameter to modify; c) thermal comfort conditions have the highest impact of the building climatization energy uses.

Following the approach proposed by Fang et al. (Fang et al. 2012), thermal comfort was evaluated through Fanger's PMV index. Categories of thermal environmental quality based on PMV index were introduced in the European standard EN15251 (CEN 2007b). Based on the comfort category to be reached, the standard suggests set-point temperatures to be set in buildings, as reported in Table 5-10.

Table 5-10: EN15251 Indoor Environmental Quality categories for thermal comfort requirements for spaces with sedentary activities

Cat.	Applicability	PMV	Operative temperature set-point for heating [°C]	Operative temperature set-point for cooling [°C]
I	High level of expectation	-0,2 < PMV < + 0,2	21	25,5
II	Normal level of expectation	-0,5 < PMV < + 0,5	20	26
III	Moderate level of expectation	-0,7 < PMV < + 0,7	18	27
IV	Values outside the above categories	PMV < -0,7 or PMV > + 0,7	-	-

To simulate the effects of thermal comfort upgrades, the thermostat control logic in guestrooms of the Reference Hotel was varied following the scenarios drafted in the WTP questionnaire (i.e. to enhance comfort conditions of a hotel room), by running two different simulation scenarios. The baseline scenario, with normal thermal comfort conditions, was simulated by setting operative temperature set-points for heating and cooling coherent with EN15251 dispositions for II Comfort Category (CC). The upgraded scenario, with "*excellent comfort conditions*", was modeled by setting in guestrooms a comfort control mechanism that impose the operative thermostat set-point to adapt in order to meet a specified PMV value, that was set to 0 (thermal neutrality) in compliance with Comfort Category I.

Simulation results

Energy performances and energy costs related to the two scenarios of thermal conform conditions envisaged for RH guestrooms are shown in Table 5-11. In order to compare the simulation based results with the outcomes of the WTP questionnaire, daily energy costs per guestroom are presented. For the purpose of costs calculations, unitary costs of energy were derived as mean values from the analysis of energy bills of an existing 3-stars hotel located in Turin (natural gas=0,08 €/kWh; electricity=0,23 €/kWh) and the average number of nights spent in 3-stars hotels was derived from Istat. Coming to results, improving comfort conditions in guestrooms led to a 10% increase in primary energy consumption and to a 9% increase in the annual energy costs of the hotel. In specific terms, this extra energy use would cost to the hotelier 0,25 €/(room*day), obtained by dividing the daily extra energy costs (4438/365=12,16 €/day) by the number of guestrooms of the RH (N=49). Recalling results shown in section 5.7.2, Table 5-7, it is evident that guests' valuation of satisfying comfort conditions, monetized in a mean marginal WTP of 11,47 €/(room*night), goes much beyond the actual energy costs of improved indoor thermal quality. On the other hand, it must be noted that the obtained WTP was related to the improvements of all the main aspects related to indoor comfort (thermal, IAQ, visual, acoustic), while the estimated extra costs dealt with better thermal conditions only.

Table 5-11: Energy performance and energy cost of the RH models with different thermostat settings. Note: II CC Op.T.= Thermostat control setting based on Operative Temperature set-points for II comfort Category; I CC PMV = thermostat settings based on maintaining PMV with the I comfort category limits.

			II CC (Op.T.)	**I CC (PMV)**	**Variation**	
					net	%
Energy Perf.	Primary Energy per Conditioned Building Area	kWh/(m^{2}y)	322,11	354,63	32,52	10%
	Electricity per Conditioned Building Area	kWh/(m^{2}y)	103,07	108,84	5,77	6%
	Natural Gas per Conditioned Building Area	kWh/(m^{2}y)	69,23	85,26	16,03	23%
Energy Costs	Total Energy Costs	€/y	49718,53	54156,54	4438,01	9%
Specific Energy Costs	Electricity Costs per Conditioned Building Area	€/(m^{2}y)	23,71	25,03	1,33	6%
	Natural Gas Costs per Conditioned Building Area	€/(m^{2}y)	5,54	6,82	1,28	23%
	Total Energy Costs per Conditioned Building Area	€/(m^{2}y)	29,24	31,85	2,61	9%
	Total Energy Costs per Room per Day	€/(room* day)	2,78	3,03	0,25	

Beside costs, the simulated thermal comfort conditions were investigated in order to verify the coherence between imposed conditions (i.e. thermostat settings) and perceived comfort (i.e. PMV values during the yearly simulation). The monthly PMV values during occupied hours of a thermal zone representing the RH typical guestrooms floor were analysed for the two simulated scenarios. Results are shown in Figure 5-9. As expected, the baseline model ("II CC Op. Temp."), where thermostat is set according to II Comfort Category requirements, has low thermal comfort performances. The comfort level of the upgraded model ("I CC PMV guestrooms"), on the contrary, lies most of the time in Comfort Category I. However, it is worth noting that in no scenario the monthly PMV level always falls within the imposed comfort category limits. It may be inferred that the building system is not able to deliver the required performance because of the very poor envelope thermal performances. Indeed, the very high thermal transmittance of the envelope components deeply affects their surface temperature and, consequently, the mean radiant temperature of the thermal zone. Provided that operative temperature is calculated as the weighted average of the mean radiant and ambient air temperatures, the influence of the thermal properties of the envelope on the perceived comfort conditions becomes evident. These findings suggest envelope-related Energy Efficiency Measures (EEMs) as necessary to guarantee excellent thermal comfort conditions in the RH. Moreover, EEMs have the potential to reduce the energy costs and, consequently, to lower the extra energy cost of improving thermal comfort. This scenario result in a win-win situation for a hotel business, where at the same time operational costs lessens and guests' satisfaction increases, as envisaged by the engineering approach to comfort monetization previously listed (Clinch & Healy 2003; Fang et al. 2012; Sartori et al. 2014). Although these interventions may require capital intensive investments, they have relevant additional positive effects on the business success; they can improve the visual and acoustic indoor environmental performances and renew the overall image of the hotel, in line with new green trends and CO_2 requirements.

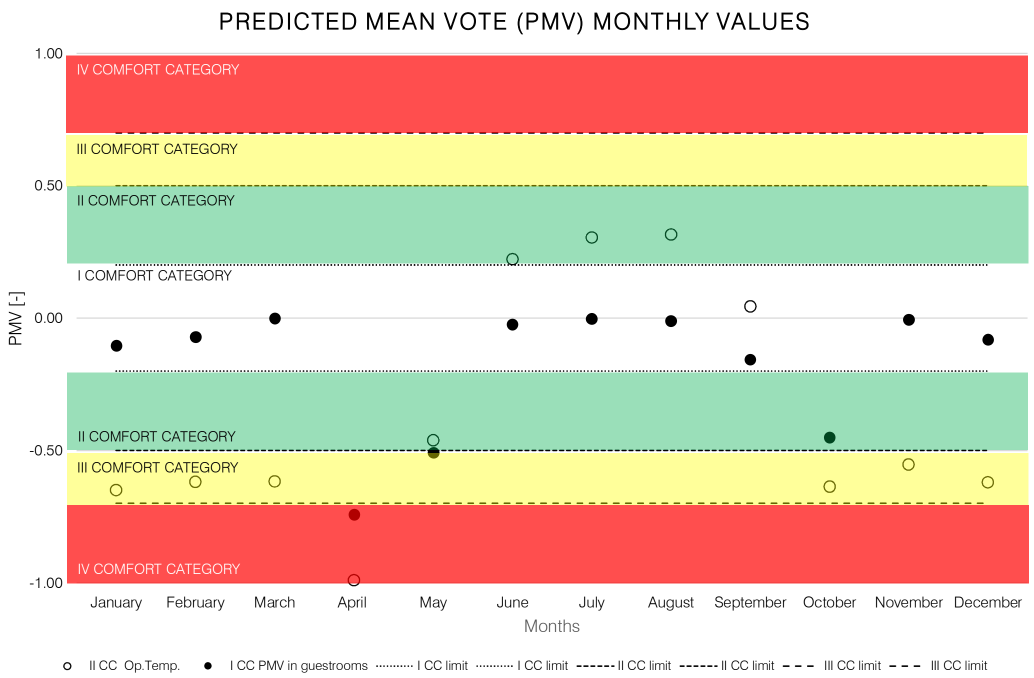


Figure 5-9: Average monthly values of PMV for a typical guestrooms thermal zone of the RH

5.7.4 Discussion

The combined application of econometric and engineering approaches to monetize comfort, here tested, revealed that comfort co-benefits are highly valued by hotel guests.

In terms of willingness to pay, the outcome of the CVM revealed that frequency distributions and amounts of WTP of interviewees for improved IEQ were higher than guests' WTP for staying in green hotels. Particularly, objects of comparison were results from the WTP investigations performed by Manaktola and Jauhari (Manaktola & Jauhari 2007) and Kang et al. (Kang et al. 2012), where the same investigation methodology of this study was applied. WTP responses are summarized in Table 5-12.

Table 5-12 Comparison of WTP results for comfort and green initiatives

Attribute		WTP (extra % of the bill) [%]														REF.
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11 - 15**	**16 - 20**	**> 20**	
Comfort	Rel. freq. of answer [%]	17,9	0,4	-	1,8	0,4	-	9,4	-	-	-	1,8	28,6	6,7	33,0	this study
Green initiatives		85,0		9,0			6,0					-				a
		33,6			37,4					23,5			3,7	0,9	0,9	b

a (Manaktola & Jauhari 2007)
b (Kang et al. 2012)

The different composition of the interviewees' sample does not allow a direct comparison among results. Nonetheless, some interesting conclusion can be drawn from the presented figures: when dealing with comfort related WTP, less zero-bids were detected and a marginal WTP higher than 11% was much more frequent, stated by 68,3% of the sample. These findings confirm the different relevance between core and ancillary functions of accommodation structures. Providing hotel guests with tangible comfort is an essential attribute, to which guests are more sensitive. On the contrary, green initiatives offer to guests intangible benefits, related to the purchase of moral satisfaction (Christy et al. 1996), whose perceived economic value is lower.

Coming to figures related to our case study, the average marginal WTP derived from interviewees' answer was 11,47 €/nights – a 14% increase in the room rate – against a negligible energy cost increase of 0,25 €/day (+9%). However, while the valued co-benefit took into account all parameters contributing to a comfortable indoor environment, extra costs considered thermal satisfaction only. In the RH, increasing ventilation rates, reducing noise annoyance, and increasing natural light, would entail the implementation to system and envelope-related EEMs, such as the installation of a mechanical ventilation system and windows substitution. In this scenario, the extra costs related to comfort increase would raise, including investment costs for the implementation of energy efficiency measures. Moreover, from a simulation-based verification of comfort conditions in the upgraded model of RH, it emerged that, in hotels with very poor envelope thermal performances EEMs may be necessary to provide guests with constantly optimal thermal comfort conditions as well. These results suggest investments in energy efficiency as the key to exploit the potential of comfort-related co-benefits in existing accommodation structures.

Further investigations on the monetary value of high IEQ could follow two different pathways, one based on the economic approach, the other on the engineering one. From the economic standpoint, a Discrete Choice Experiment could be carried on in order to estimate respondents' preferences for each aspect of indoor comfort (visual, acoustic, thermal, IAQ). From an engineering perspective, instead, next steps of the research should focus on the quantification of the extra costs of envelope and system upgrades, for a more coherent and comprehensive comparison among extra costs and co-benefits of an overall IEQ improvement. These extra costs could be considered, for instance, as the investment cost to improve opaque and transparent envelope of buildings; insulating the opaque envelope would improve the efficiency of the building, replacing the old windows would ensure a higher sound insulation.

Beyond the numerical findings, context-dependent and based on simulation assumptions, this application proved comfort co-benefits as key factors to be included in the economic/financial evaluation of retrofit interventions. Additionally, comfort valuation should not be merely based on simulation results, as the perception of indoor comfort conditions is strongly linked to both objective and subjective parameters.

5.8 Key findings

The main research findings of this chapter build upon the recent literature that promotes the inclusion of co-benefits in the valuation of energy efficiency intervention in buildings. First, a list of all potential co-benefits of energy efficiency projects listed in relevant studies was compiled, where benefits were categorized based on area of influence (e.g. health effects, economic effects) and evaluative perspective (e.g. financial, economic).

The listed benefits were object of a first analysis aimed at including them in the financial evaluation of retrofit options for a hotel building. To this purpose the cost-optimal methodology was the starting point for proposing a *global cost-benefit* formula. In the case-specific application of this formula, incentives, productivity, service price and market value benefits were monetized for different retrofit options. The inclusion of these co-benefits in the cost-optimal methodology proved to have a great potential in modifying investors' perception about the convenience of retrofit interventions. Specifically, this application revealed that benefits related to an increase in service price have the biggest impact on global costs. The leading role of service price in modifying the profitability of an energy efficiency intervention justify the importance given by hoteliers to green labels, which are typically considered by costumers as proxies for high performing hotels. Main weakness of the proposed findings is that the envisaged co-benefits monetization options were derived from literature, while in reality co-benefits are strongly linked to the context. Therefore, these results cannot be taken as realistic quantitative references.

To directly face the challenge of monetization of co-benefits, the research focus then shifted to a proposal for quantifying comfort co-benefits, which has been poorly explored in scientific literature so far. An economic approach to value comfort benefits was compared to an engineering approach to value comfort costs in hotel guestrooms. Benefits were monetized by applying the Contingent Valuation Method to quantify the willingness to pay for staying in comfortable guestrooms for over 200 respondents. Costs of improved thermal comfort conditions were monetized by calculating the extra energy costs of improving comfort condition in guestrooms of a reference hotel building. Results highlighted that comfort co-benefits are highly valued by hotel guests and that for a hotelier the costs of providing comfortable indoor conditions to guests are much lower than the benefits deriving from it. However, once again these findings do not represent universally valid quantitative references, as they are strongly interwoven with the context in which CVM was applied.

Despite the questionable reliability of the numerical findings presented, the pieces of research here proposed represent interesting sparks to tackle the issue of co-benefits in energy efficiency projects. On one side, a proposal for including co-benefits in well-established retrofit projects valuation methods is presented. On the other side, valuation methods for non-market goods are proposed as a possible solution to monetize co-benefits, which is the main barrier for their inclusion in the traditional evaluative discipline. Additionally, both case studies applications confirmed the leading role that literature attribute to co-benefits in the success of energy efficiency projects.

Chapter 6

6. Conclusion

6.1 Conclusive summary

Leading goal of this PhD dissertation was to support the definition of effective strategies to improve the energy performance of the European existing building stock. Contributions were addressed to propose inputs for long-term energy analysis and for boosting private investments in energy efficiency projects.

The research boundaries were delineated by focusing on existing non-residential, multi-functional buildings, that are nowadays poorly studied due to their heterogeneous nature. These buildings were first described, to ease their inclusion in energy models. Then, they were used as objects of energy and financial evaluations. Indeed, in this thesis the link between energy and financial performance of retrofit interventions was elected as chief topic to be investigated, as it constitutes the main driver for private investments in energy efficiency interventions in buildings. Given the goal and the boundaries of the research, four research questions arose and were addressed within the PhD research path:

1) How to include non-residential buildings in buildings energy models?
2) Is the accommodation sector effectively reducing its energy use?
3) Is NZEB level cost-optimal for multi-functional buildings?
4) How to include co-benefits in valuation procedures?

These **research questions** were elicited in Chapter 1 and they were used to structure the dissertation contents. A chapter was dedicated to each research question. In this concluding section, instead, the **answers** proposed by the candidate are listed, summing up the findings presented throughout the thesis.

6.1.1 How to include non-residential buildings in buildings energy models?

Bottom up engineering models are the most used tools for depicting the building stock energy use patterns, thanks to their ability to describe present scenarios as well as to compare several development alternatives (Swan & Ugursal 2009). At the European level, most of these models exploits archetypes, which are single-building models representative of a larger sample of the building stock. At present, EU archetypes (or Reference Buildings) are mainly developed for residential buildings only and, consequently, bottom up-engineering models only describe the potential development trajectories for the residential stock (Kavgic et al. 2010). In order to enrich the understanding of EU building stock as a whole, these models should be complemented with archetypes representing non-residential buildings as well.

Hence, in the thesis **a modelling method for creating archetypes of non-residential, multi-functional building was proposed**. In this broad and heterogeneous building category, a variety of end-uses may or may not be included in the energy evaluation. Thus, a rationale for the classification of these end-uses was developed. Based on the EU guiding principles exploited for the identification of energy uses in buildings, complex multi-functional buildings were intended as a set of single functions, which can be classified into typical and extra. The modeling problem was therefore simplified, allowing the use of well-established Reference Buildings modelling methods.

The obtained archetypes could be implemented in the existing building stock models as single elements, (i.e. each building model is an archetype, constituted by typical and extra functions), or they could represent a transversal category of multi-functional buildings showing similar typical energy uses, to which extra energy uses can be added based on the features of the stock to be represented.

See Chapter 2 for the full development of this part of the PhD research.

6.1.2 Is the accommodation sector effectively reducing its energy use?

The information retrieved from literature about the energy use of hotel buildings highlights how poor is the actual knowledge of this building category, which well exemplify the multi-functional building stock. Despite the global attention towards Sustainable Tourism, in facts **there are no reliable benchmarks for the European hotel stock**.

In this general lack of knowledge, green labels are typically considered by costumers as proxies of environmental friendly behaviors of hotels. Applications of willingness-to-pay methods (e.g. (Kuminoff et al. 2010; Kang et al. 2012)) found that guests were willing to pay a price-premium for lodging in hotels implementing green practices. However, the comparative analysis among hotel-related green labels performed in the framework of this thesis denounced that **green labels do not ensure the low energy use or environmental impact of the labelled structures**. Nineteen third-party, multi-criteria green certification for hotels, with different national and international coverages, were analyzed with a specific focus on their energy efficiency requirements. Results highlighted the impossibility to compare different labels in terms of effectiveness in greening the hotel to which they are applied and the lack of quantitative reduction targets.

See Chapter 3 for the full development of this part of the PhD research.

6.1.3 Is the NZEB level cost-optimal for multi-functional buildings?

The answer to this question necessarily required the contextualization of the problem for a defined building type and country. Indeed, Nearly Zero Energy requirements vary from one EU Member State to another and the application of the cost-optimal analysis requires the definition of a Reference Building to which several design solutions can be applied.

The choice made in this dissertation was to focus on existing hotel buildings in Italy because:

a) Existing building are the vast majority of the EU building stock;
b) Hotels are fitting examples of multi-functional buildings;
c) Italian hotels represent alone the 18% of the EU accommodation structures;

d) In Italy there is an official NZEB definition available, which apply to hotel buildings as well.

Based on these premises, the research strategy was two-folded, focusing on a fictional Reference Hotel representative of a large share of the Italian hotel stock and on real hotels. From both perspectives, findings converged on similar conclusions. **The analysis carried out for the Refence Hotel revealed that cost-optimal retrofit solutions do not fulfil the NZEB nor the minimum Italian energy requirements**, due to the relevant weight that electricity consumptions have in the overall energy use of the building. **The analyses on real hotels revealed that, due to the high share of electricity energy uses, cost-optimal retrofit solutions may not include measures effectively improving the building energy performances (e.g. heating and cooling)**. It may be inferred that, in order to drive private investors towards a deep energy retrofit of their business activities, new valuation methods should be adopted. For instance, the analysis on thermal comfort conditions for a typical guestroom of the Reference Hotels showed that most "expensive" solutions, many of whom were NZEBs solutions, had the best thermal comfort performances among the envisaged options.

See Chapter 4 for the full development of this part of the PhD research.

6.1.4 How to include co-benefits in valuation procedures?

The answer to the previous research question paved the way to investigate how valuation procedures could be exploited in order to make NZEB retrofit solutions appealing for private investors. Specifically, the propositions for which energy efficiency interventions entail a wide range of non-energy benefits (co-benefits), put forward by several international studies, was the starting point the investigations performed in this thesis.

Two different strategies were pursued. First, based on literature review, **co-benefits of improved energy performance for a Reference Hotel were monetized and included in the cost-optimal analysis**. The inclusion of these co-benefits in the cost-optimal methodology proved to have a great potential in modifying investors' perception about the convenience of retrofit interventions. Specifically, this application revealed that benefits related to an increase in service price have the biggest impact on global costs. As green labels were proved to entail a price premium for guestrooms, the importance given by hoteliers to green labels is justified. Then, **the issue of monetizing non-energy benefits was faced**

directly: a technique to value non-market goods was applied to monetize comfort. Findings proved that guests' willingness to pay for comfortable indoor conditions is much higher than the hoteliers' extra costs for providing them.

Due to the context-dependent nature of co-benefits, the findings of the two applications do not represent generally applicable quantitative benchmarks. Nonetheless, **they confirm the leading role that literature attribute to co-benefits in the success of energy efficiency projects**.

See Chapter 5 for the full development of this part of the PhD research.

6.2 Research contributions

By focusing on multi-functional buildings – and hotel buildings in particular – in terms of their inclusion in EU building policies, this PhD dissertation is a rather unique monography. The analysis of existing literature on the European building stock energy features revealed that the most complex non-residential building categories (e.g. hotels, wholesale and retail, hospitals) still lack of robust analyses in terms of the composition and energy patterns.

In this sense, all the research answers listed in the previous paragraphs represent original research contributions of this PhD path towards a better understanding of the non-residential building stock. However, findings can be differentiated based on their originality. Indeed, some outcomes derived from the application of well-established methodologies, while others represent novelties proposed by the author in collaboration with her research team. For instance, the method for modeling multi-functional buildings (mfBs), is based on one side on the original author's **proposal to split the energy use of any multi-functional buildings into "typical" and "extra" energy uses**, on the other side it relies on acknowledged modelling methods (Corgnati et al. 2013) to model the defined typical and extra functions of a Reference multi-functional building. **The Reference Italian Hotel**, obtained by implementing the proposed mfBs modeling method, represents another original outcome, drafted based on the statistical data available for Italian hotels, collected from various and heterogeneous sources. The focus on hotel buildings led the author to point the attention to the effectiveness of hotel-related green labels in measuring the energy/environmental performances of hotels. **The comparative framework set up to analyze the various labels** is an original outcome of the analysis and it **constitutes a precious basis to critically compare green labels**. The well-established and EU-promoted cost-optimal methodology was first applied in its traditional form, to spot the gap between cost-optimal and NZEB energy performance for real and fictional Italian hotels. In these applications, the most interesting findings are represented by the Italian NZEB limit and the spotted financial gap. In the field of energy end economic evaluations, the major novelties are represented by the proposed **approaches to include co-benefits in the evaluation of retrofit options**. On one side, the author further developed early proposals (Becchio, Corgnati, et al. 2015; Gvozdenović et al. 2014) of including benefits in the cost-optimal formula and she first applied this approach to a hotel building. On the other side, **a new methodologic approach was proposed to valuate indoor comfort**. To the author's knowledge, in the framework of this thesis the Contigent Valuation Method was applied for the first time to monetize occupants' comfort, going beyond the typical engineering approach proposed in literature.

6.3 Future work

This dissertation reports the first steps towards the effective inclusion of multi-functional buildings in EU energy policies. Hence, all the mentioned findings require further research, in order to evolve from proposals to actual methods or conclusive results.

The modelling method for Reference Multi-functional buildings will need to be applied to other building categories to further test its applicability and it strongly requires validation based on real data. As the knowledge of the non-residential stock is generally blurred, more information would be needed for better describing the typical and extra functions of non-residential buildings and, in a vicious circle, to validate the information obtained through Reference Buildings. In this view, the modelled Italian Reference Hotel features, energy use patterns and uses still miss feedbacks. In the same line, the potential for application of the modelling approach at the urban scale, where the typical energy use of a generic Reference multi-functional building can be used to model a wide range of non-residential buildings, needs to be verified.

The traditional application of the cost-optimal application performed in this thesis has room for improvement as well. At present, energy efficiency measures and their combinations were arbitrary decided by the author in view of complying with national performance requirements. This choice aimed at replicating the most common design approach to the retrofit of an existing building, that a small design firm hired by a private investor could follow. However, this elimination approach cannot guarantee a global cost-optimal solution, as only a limited number of design solutions is tested. To overcome this problem while still avoiding an overwhelming calculation burden, recent academic studies investigated cost-optimal levels of energy performance by exploiting computer-based optimization techniques (Hamdy et al. 2013; Ferrara et al. 2014). In general terms, these studies couple the use of a building simulation programs with an optimization engine, so that the optimization problem is solved with iterative methods driven by optimization algorithms. In the context of cost-optimal analysis, the optimization problem is typically multi-objective, with an objective function related to primary energy use and another objective function related to global cost. These algorithms construct sequences of progressively better approximations to a solution. In is worth noting that multi-objective optimizations problem can include even more objective functions, aiming at exploring different parameters. For instance, Penna et al. and Ascione et al. (Penna et al. 2015; Ascione, Bianco, De Stasio, et al. 2016) introduced the evaluation of the indoor thermal comfort in their multi-objective optimization analysis of energy efficiency measures in existing buildings. Even if these techniques remain far from the working realities of design firms, their exploitation potential is high for the definition of cost-optimal level of energy performance at the legislative sphere, where research institutes are typically in charge of the scientific work supporting the figures imposed in the mandatory requirements.

Finally, the topic of economic valuation of co-benefits related to energy efficiency projects deserves a much wider investigation. On one side, different valuation methods for non-market goods, such as Choice Experiment and Hedonic Price methods, should be applied to answer to the same research questions proposed in this thesis (e.g. comfort in hotel guestrooms). The same investigations could be then replicated in different locations, to investigate the influence of the context. These developments would allow the researcher to test the reliability of the findings presented in this thesis. On the other hand, all these valuation methods could be applied to monetize other co-benefits and to other building types, in order to set up reliable benchmarks that could then be implemented in traditional valuation techniques for energy efficiency projects, such as the cost-optimal methodology or the cost-benefit analysis.

A conclusive remark relates with the human factor, hidden behind any investors' decisions. Indeed, bounded rationality is one of the three pillars of the energy efficiency gap spotted by Howarth (Howarth 2004). Beside the envisioned operative progresses in the energy and economic aspects of this PhD research, a further conceptual leap will be needed in future developments to include motivational drivers in the perceived convenience of energy efficiency interventions. In the field of comfort studies, for instance, a growing branch of researches states the need to achieve a deeper understanding of the motivation structure towards the concept of “forgiveness” and energy-saving behaviors (Hong et al. 2015; D’Oca et al. 2016). By embracing the motivational approach, investors and occupants may be supposed to prefer energy saving settings, regardless of the financial convenience or of the indoor comfort level.

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PART II

Paper I

NZEB definitions in Europe

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nZEB definitions in Europe

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Within European neZEH project, national nZEB definitions were collected. Ten available definitions revealed to be remarkably different by content and ambition level. Not all of them were based on primary energy, and values between 20 and 200 do not allow meaningful comparison. The situation calls for European level guidance and shows the need to harmonize basic principles of energy calculations.

Keywords: nearly zero energy buildings, cost optimality, energy use, energy performance, energy targets.

From cost optimal performance to nZEB

Cost optimal calculations according to European methodology [1] were reported in last year and presented in EPBD Concerted Action meeting in October. The results were consistent as the performance levels of optimal solutions were quite similar in countries with similar climate. The coherence among results obtained by different institutions in different countries demonstrates the power of European delegated regulation that provided a common calculation methodology at the EU level – harmonization happened immediately and most of Member States (MS) were capable to conduct a large set of demanding calculations with many combinations. However, the philosophy of cost optimality as a first step towards nZEB seems not fully utilized in MS. Cost optimal calculations included high efficiency and renewable energy cases, relevant for the definition of nZEB, but the results of the calculations and analysis have not had much effect on the national nZEB defintions. In fact, the similar coherency cannot be found among the national applications of the definition of nZEB submitted by MS in last year. This was done as a part of national plans for increasing the number of nZEBs where MS were required to report the detailed application of the definition of nZEB including a numerical indicator of primary energy expressed in kWh/m² per year. Based on these national plans, the Commission published a progress report of nZEB 7.10.2013 [2] highlighting that 10 MS had more or less a full definition in place. More detailed information was available from the report of the EPBD Concerted Action meeting [3] and also from national codes, where some countries have already included nZEB values.

Based on these references, the available data of nZEB definitions was grouped according to ECOFYS classification [4] into five European climate zones as shown in **Figure 1**, in order to study the variation in primary energy values and other relevant parameters within comparable climate zones.

National nZEB definitions

An overview of the currently available definitions is shown in **Table 1**. The data covers primary energy and renewable energy share (RES) indicators, as well as inclusion of energy flows in different building types. The majority of countries (7 out of 10) are using primary energy indicator, but in some cases it covers only heating. In 3 countries out of 10, all major energy flows are included, i.e. in these countries the calculated energy use is comparable to measured energy use. In the rest of countries, mainly appliances and also lighting

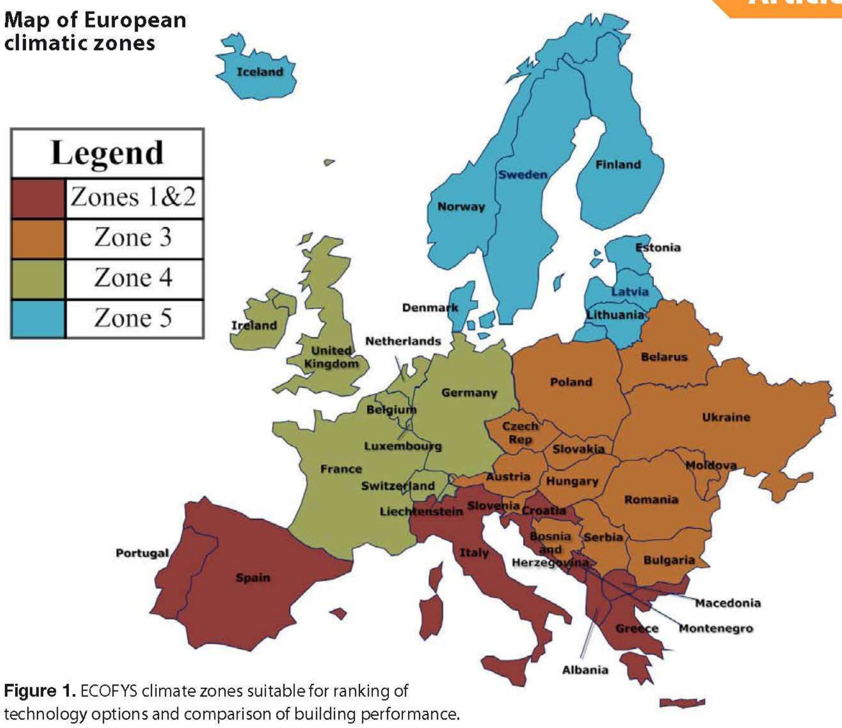

Figure 1. ECOFYS climate zones suitable for ranking of technology options and comparison of building performance.

in residential buildings were not included, despite of increasing importance of these components in the energy balance. In nZEB non-residential case studies (some examples are shown in **Table 2**) the appliances have become a major component in energy balance, often accounting for 40–50 kWh/m^{2}y primary energy. Some countries have not yet implemented RES calculation (on site renewable energy production) to present calculation frames, and half of countries have set specific indicator for RES in nZEB definition.

The ambition of nZEB definitions may be assessed with comparison to current minimum energy performance requirements. Such comparison was straightforward for Denmark and Estonia, where current EP requirements are:

- Denmark 71.3 + 1650/A kWh/m^{2}y for non-residential buildings, where A is gross floor area;
- Estonia 160 kWh/m^{2}y for office buildings.

In Estonia, nZEB value of 100 kWh/m^{2}y means the reduction by factor of 1.6. In Denmark, changes in primary energy factors are also to be taken into account. Current factors of 2.5 and 1.0 for electricity and district heat will change to 1.8 and 0.6 respectively in 2020. This results as the reduction by factor of about 2.0.

nZEB definitions were set in most countries for residential and non-residential buildings, i.e. based only on two primary energy values. Considering non-residential buildings as a single category it means that all buildings are calculated with same occupancy, ventilation rate, lighting, appliances and operation time. This approach will make no difference between offices, hospitals, schools or retail buildings, which easily show a variation in energy use by factor 3 because of different uses. If design solutions would be selected based on nZEB primary energy requirements and standard "non-residential" use of a building, in many cases optimal solutions will not be found. Such "non-residential" use will eliminate for instance the effect of lighting in shopping malls (the highest energy use component in reality) as well as the effect of demand control ventilation in schools and other rooms with high occupancy and ventilation rate. Consequently the calculated heating and cooling loads

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Table 1. Overview of the NZEB numerical definition currently available in Europe.

Zone	Country	NZEB definition – Energy Performance (EP): EP-value	Unit	RES in the EP calc.	Metric	Energy uses included	Building type		RES	Reference: National legislation providing the nZEB definition	References used for the table: Ref. for EP	Ref. for RES
Zone 1-2	Cyprus	180	kWh/m²y	NO	Primary energy	heating, cooling, DHW, lighting		Residential	25%	NZEB Action Plan	[5]	[5]
		210	kWh/m²y	NO	Primary energy			Non-residential	25%		[5]	[5]
Zone 3	Slovakia	32	kWh/m²y	N.D.	Primary energy	heating, DHW	Apartment buildings	Residential	50%	-	[3]	[3]
		54	kWh/m²y	N.D.	Primary energy		Family houses		50%	-	[3]	[3]
		60	kWh/m²y	N.D.	Primary energy	heating, cooling, ventilation, DHW, lighting	Office	Non-residential	50%	-	[3]	[3]
		34	kWh/m²y	N.D.	Primary energy		Schools		50%	-	[3]	[3]
Zone 4	Belgium BXL	45	kWh/m²y	YES	Primary energy	heating, DHW, appliances	Individual dwellings	Residential	-	Brussels Air, Climate and Energy Code	[5]	-
		95 - 2,5*(V/S)	kWh/m²y	YES	Primary energy	heating, cooling, DHW, lighting, appliances	Office buildings	Non-residential	-		[5]	-
		95 - 2,5*(V/S)	kWh/m²y	YES	Primary energy	heating, cooling, DHW, appliances	Schools		-		[5]	-
	Belgium Walloon	60	kWh/m²y	N.D.	Primary energy	heating, DHW, appliances	Residential buildings, schools office and service buildings	Residential/ Non-residential	50%	Regional Policy Statement	[2]	[5]
	Belgium Flemish	30	kWh/m²/y	YES	Primary Energy	heating, cooling, ventilation, DHW, auxiliary systems		Residential	>10 kWh/m²y	Energy Decree	[5]	[5]
		40	kWh/m²y	YES	Primary Energy		Office buildings, schools	Non-residential	>10 kWh/m²y		[5]	[5]
	France	50	kWh/m²y	NO	Primary energy	heating, cooling, ventilation, DHW, lighting, auxiliary systems		Residential	-	RT2012	[5]	
		70	kWh/m²y	NO	Primary energy		Office buildings non-air-cond.	Non-residential	-		[5]	
		110	kWh/m²y	NO	Primary energy		Office buildings air-cond.		-		[5]	
	Ireland	45	kWh/m²y	N.D.	Energy load	heating, ventilation, DHW, lighting		Residential	-	Building Regulation Part L amendement	[5]	
	Netherlands	0	[-]	YES	Energy performance coefficient (EPC)	heating, cooling, ventilation, DHW, lighting		Residential/ Non-residential	not quantified, but necessary	EPG 2012	[5]	
Zone 5	Denmark	20	kWh/m²y	YES	Primary Energy	heating, cooling, ventilation, DWH		Residential	51% - 56%	BR10	[5]	[2]
		25	kWh/m²y	YES	Primary Energy	heating, cooling, ventilation, DHW, lighting		Non-residential	51% - 56%		[5]	[2]
	Estonia	50	kWh/m²y	YES	Primary Energy	heating, cooling, ventilation, DHW, lighting, HVAC auxiliary, appliances	Detached houses	Residential	-	VV No 68:2012	[6]	-
		100	kWh/m²y	YES	Primary Energy		Apartment buildings		-		[6]	-
		100	kWh/m²y	YES	Primary Energy		Office buildings	Non-residential	-		[6]	-
		130	kWh/m²y	YES	Primary energy		Hotels and restaurants		-		VV No 68:2012	
		120	kWh/m²y	YES	Primary energy		Public buildings		-		VV No 68:2012	
		130	kWh/m²y	YES	Primary energy		Shopping malls		-		VV No 68:2012	
		90	kWh/m²y	YES	Primary energy		Schools		-		VV No 68:2012	
		100	kWh/m²y	YES	Primary energy		Day care centres		-		VV No 68:2012	
		270	kWh/m²y	YES	Primary energy		Hospitals		-		VV No 68:2012	
	Latvia	95	kWh/m²y	N.D.	Primary energy	heating, cooling, ventilation, DHW, lighting		Residential/ Non-residential	-	Cabinet Regulation N° 383 from 09.07.2013	[3]	-
	Lithuania	<0,25	[-]	N.D.	Energy performance indicator C	heating		Residential/ Non-residential	50%	Building Technical Regulation STR 2.01.09:2012	[5]	[3]

Table 2. Energy data from four nZEB office buildings. Delivered heating is in first building a fuel and in last one district heat. Two other buildings have heat pumps, and delivered heating is electricity. Delivered cooling is in all buildings electricity. On site electricity generation is with PV in three buildings and bio-CHP in one building. All values in the table are in kWh/m²y.

Climate zone	City, country	Delivered energy Heating	Cooling	Fans&pumps	Lighting	Appliances	On site electricity	Primary energy
4	Dion France	10.5	2.4	6.5	3.7	21.2	-15.6	**44**
4	Gland Switzerland	6	6.7	8.1	16.3	26.8	-30.9	**66**
4	Hoofddrop Holland	13.3	3.3	17.5	21.1	19.2	-40.4	**68**
5	Helsinki Finland	38.3	0.3	9.4	12.5	19.3	-7.1	**96**

and energies can be very far from reality. The wide gap in energy use between different non-residential building types is illustrated in the **Table 1** with the Estonian values, showing a variation between 100 and 270 kWh/m²y for seven non-residential building types.

In setting nZEB targets the experience from nZEB pilot buildings is worth to utilize. In the following, detailed energy data of four nZEB office buildings located in climate zones 4 and 5, published in [7], are reported with the aim to compare national nZEB values to the values of real case studies. **Table 2** shows a summary of delivered and primary energy of these buildings. From the first building, measured data is used, from others simulated energy use is reported. To be comparable, for all buildings the following primary energy factors were applied:

- 0.7 for heating (district heat or biomass);
- 2.0 for electricity.

Remarks and conclusions

The review of available national nZEB definitions shows remarkably high variation in nZEB primary energy values being between 20 and 200 kWh/m²y in ten countries. The high variation applied even within the same building type in countries with similar climate. It is partly due to different energy uses included and partly due to different level of ambition in the definitions.

Energy data reported in available nZEB case studies of office buildings was supporting with some reservations Belgian and French (zone 4) and Estonian (zone 5) nZEB values. Generally, energy data of nZEB case studies seem to provide more reliable benchmarks than that from first national nZEB definitions, which in many cases seem suffering under inconsistent calculation methodologies and do not account all energy flows. The latter leads to situation where calculated energy use could represent only a small fraction of measured energy use in real buildings.

Compared to current energy performance minimum requirements of office buildings, nZEB primary energy values showed a reduction by factor of 1.6 in Estonia and by about 2 in Denmark if changes in primary energy factors were also accounted. For other countries, enough detailed data to calculate the reduction percentage was not available.

It can be concluded that Member States need more guidance in order to set consistent and comparable nZEB values with equal ambition levels. For some reason, the European cost optimal methodology seems not utilized in all countries when defining nZEB – it could be speculated that existing energy calculation frames and methodologies are too different to enable easy implementation of those calculation principles.

Very limited number of building types used in national nZEB definitions, often just residential and non-residential, was alarming and shows that majority of countries cannot tackle the eight building types specified in EPBD recast Annex [8].

Definition of standard uses for common building types would be an important task for European standardisation, which can be addressed in ongoing revision of EPBD standards, expected to be completed due 2015. Hourly profiles for occupancy, appliances, lighting and domestic hot water would be required to calculate how much of on site renewable energy production could be utilized in the building and how much needs to be exported. Without this information, alternative design solutions cannot be adequately compared in nZEB buildings. ■

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Paper II

A customized modelling approach for multi-functional buildings – Application to an Italian Reference Hotel

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A customized modelling approach for multi-functional buildings – Application to an Italian Reference Hotel

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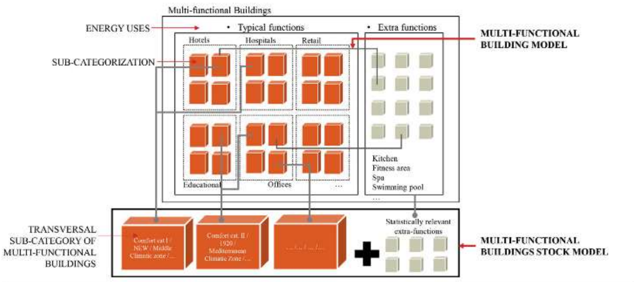
HIGHLIGHTS

- Reference Buildings are essential for bottom-up models of the building stock.
- Non-residential buildings are under-represented in energy models of the EU stock.
- Multi-functional buildings are an important share of the non-residential stock.
- Multi-functional buildings are modelled differentiating typical and extra functions.
- The proposed modelling method is applied to define an Italian Reference Hotel.

GRAPHICAL ABSTRACT



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ABSTRACT

In the forthcoming European low-carbon energy system, the building stock plays a major role in the demand sector. Therefore, in order to develop robust scenario analysis towards the success of the low-carbon goals, a trustful characterization of the building stock is required. Reference Buildings are often the base of these building stock models, but, at present, an uneven level of development between residential and non-residential Reference Buildings is detected. The present paper contributes to fill this knowledge gap by proposing a method to model Reference multi-functional Buildings. Multi-functional buildings represent an important share of the non-residential buildings stock, by embracing all buildings hosting different activities under the same roof. In order to trustfully depict their energy performances, the EU definition of Reference Buildings have to be updated. To this purpose, this study proposes a rationale to describe and model these buildings, based on the distinction between their typical and extra energy uses. In order to test the proposed methodology, it was applied to the definition a Reference Hotel in Italy, with the additional aim to provide support material to the national energy and tourism policies.

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1. Introduction

The European Commission's low-carbon goals envisage that by 2050 European citizens "will live and work in low-energy, low-emission buildings with intelligent heating and cooling systems. [They] will drive electric and hybrid cars and live in cleaner cities with less air pollution and better public transport" [1]. The image of a low-carbon society dismantles the traditional link

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"energy - economic development - GHG emission" by promoting a winning interaction among Energy, Economic development and the Environment, usually referred to as the 3Es or trilemma concept [2]. In this vision, the careful design of an energy system results in optimum combinations of resources and technologies in order to drastically reduce GHG emissions. Indeed, any energy system has constant components: the energy resources, the conversion technologies and the energy demand sectors [3]. The application of energy models to these elements allows the representation and exploitation of the complex interactions within the energy system.

In the forthcoming European low-carbon energy system, the building stock plays a major role in the demand sector. Buildings are responsible for 36% of the total GHG emission [4] and a 90% reduction is required from this sector by the mid-century [1] for the success of the low carbon goal. Energy models of the building stock are therefore necessary to assist the rational implementation of low carbon policies. They have the task of assessing the "baseline" demand and of being the test-bed for energy and emission reduction strategies (resource-technology combinations), aimed at understanding the possible future trends for energy consumption in urban contexts. This modelling approach towards the definition of potential renovation pathways was exploited in relevant EU studies [4,5]. BPIE researchers [4] modelled the impact of different renovation pathways for the building stock, by attributing different values to three main influencing variables: rate, depth and costs of the renovation. This showed that only in those scenarios where both the rate and the depth of renovation were substantially increased, alongside rapid decarbonisation of the energy supply system, could the carbon saving ambition be achieved. In the report "Renovation tracks for Europe" [5], a calculation model with simplified input data describing the building stock was used to quantify reduction of energy use and CO_2 emissions, financial impacts and employment effects for different renovation scenarios. Its findings revealed that the combination of renewable energies and deep building renovation was the most preferable option to successfully meet the EU CO_2-targets for 2050.

However, the heterogeneous composition of the building stock is a major issue for these long term development perspectives. The description of the non-residential building stock, in particular, remains somehow vague. Non-residential buildings are typically classified according to the main activity they host, e.g. offices, educational buildings, hospitals, hotels and restaurants, sports facilities and wholesale and retail trade services buildings. This simplified distinction in categories does not take into account of the heterogeneous nature of the activities carried on in these buildings. For instance, similar hotels may offer different services to their guests (e.g. a restaurant, a swimming pool or a spa) causing very different energy uses for apparently homogeneous buildings. These buildings, where several and diverse activities are taking place simultaneously, are generally referred to as multi-functional or multi-purpose buildings [6–8]. This category is broad and transversal and includes a large number of non-residential buildings. In order to find a rationale for the realistic modelling of these multi-functional buildings, it is necessary to recall the 3 alternative ways used to define a building [9]: (1) building as a complex *assembly of products*; (2) building as a *process* intended to provide services to users; (3) building as a *place to live*, guaranteeing comfort to its occupants. In the evaluation of the energy uses of multi-functional buildings, the interpretation of a building as a *place to live* and as a *process* coexist and alternate depending on the specific function taken into account., This paper proposes a modelling method to define Reference multi-functional Buildings (RmfBs), building upon this interpretation. The present study presents a sound literature base for the method and it develops and specifies the research work presented by Buso et al. [10], in order to contribute to a more realistic description of the existing non-residential building stock. Among the modelling techniques provided in literature, the Reference Building (RB) approach was selected. RBs can model the energy consumption of a group of similar buildings and can be used to assess the impact of specific energy and carbon reduction measures on the overall energy demand. The proposed methodology was applied to the definition a Reference Hotel (RH) in Italy, with the additional aim of providing support material to the national energy efficiency strategies in the Italian tourism sector.

2. State of the art

Several modelling techniques are available to produce robust descriptions of the existing building stock, from the aggregated to the single building level. In the followings a short overview of the most well-established building modelling approaches is provided (Section 2.1), followed by a literature review of the current understanding of the EU residential and non-residential building stock and models, in Sections 2.2 and 2.3. A final paragraph (Section 2.4) is dedicated to the current understanding of Italian hotel sector, field of application for the modelling method proposed in the followings of the paper (Sections 3 and 4).

2.1. Building stock modelling approaches

Hall and Buckley [11], based on a sound literature review, proposed a comprehensive classification scheme for energy system models, accounting for their purpose, structure, mathematical approach and technological detail. In this framework, energy models of the building stock are sectoral energy models typically built for long-term scenario analysis, in which simulation or optimization methodologies are used to define the energy demand of the sector. Main criteria for their categorization is the analytical approach, "top-down" or "bottom-up". A complete review of these approaches to buildings energy modelling was provided by Swan and Ugursal [12]. In this paragraph the main features are recalled, in order contextualize the modelling choice proposed in the following of the paper.

Top down models. "Top-down" models for national building stocks became popular in the 70's, as a consequence of the oil crisis [13]. They are applied to a whole building sector (e.g. the residential sector) to evaluate the macro-economic relations between energy consumption and changes within the sector object of analysis. Based on the factors included in the analysis, they can be divided in econometric and technological models. They require only aggregate data, which simplify the analysis but eliminate the possibility of spotting key areas of improvement. Moreover, they typically aim at fitting energy values in historical series of data and therefore they are not able to model discontinuous advances in technology.

Bottom-up models. The "bottom-up" approach, on the other hand, has the aim to identify the contribution of single end-uses towards the aggregate energy consumption of the system under consideration. The degree of resolution of these energy models can vary widely, from energy consumptions of single end-uses to those of a group of houses. Such models can therefore be exploited to represent the energy system of a city, region or nation. The popularity of this approach grew in the last decades, promoted by the International Energy Agency as a tool for local planning purposes [14]. In general, input data come from hierarchical levels less than as a sector a whole and common input data for building models include buildings geometrical, thermo-physical and operational properties. The high level of detail allows the full development of the energy use trends of a sector without long-records of historical data, the configuration of different technological options and the detection of key areas of improvements. However, the detailed description required also represent the primary drawback of this approach, due to the well-known paucity or unreliability of data. Based on the type of data inputs, the "bottom-up" approach could be further classified into sub-groups of modelling methods, broadly generalized in Statistical and Engineering. Statistical methods (SM) rely on energy consumption data and on an array of statistical techniques to regress the relationship between end-uses and energy consumption. Among the various statistical modelling techniques, regression is the most popular in building energy modelling [15]. An important pro of SM is the capability to detect the effect of occupant behavior on energy consumption. On the other hand, the low level of detail and flexibility limit the ability of SMs to evaluate alternative energy scenarios. The approach of the Engineering method (EM), instead, is based on building physics. It requires quantitative data on physically measurable variables (geometrical, thermo-physical and operational), used as input for building energy calculations, and it estimates the delivered energy of a building/sample of buildings. Different assumptions on the variables describing the model allow the modeler to develop different scenarios and to assess their impact on the whole stock energy demand and CO_2 emission. The flexibility of these models is their strongest advantage, that, however, is set off against a poor ability to include the role of behavioral factors on energy consumption, due to simulation assumptions. In their review, Swan and Ugursal [12] identifies 3 main EM techniques: distributions, archetypes and samples. Distributions account separately the energy consumption of each end-use based on the distribution and ownership of appliances. Main limitation of this approach is that it does not take into account interactions among end-uses. Archetypes are limited set of dwellings, representative of a larger stock, created by the modeler by gathering typical features of the building stock under consideration. The generated archetypes are the input data for engineering models of the building stock, as they reduce the calculation/simulation effort. Samples, differently for Archetypes, are real buildings used to portray the actual variety of the building stock. This approach requires a large sample of real buildings, with features and energy uses known. Such data intensity limited its application so far.

Hybrid models combine the two approaches by introducing technological detail within a macro-economic approach. According to the level of integration, that can be distinguished in soft-linked, when top-dons and bottom-up models are coupled, and hard-linked, when the features of the two approaches are blended is a single model [11].

Fig. 1 graphically summarizes the mentioned approaches.

2.2. Current understanding of the EU building stock

In the last years many researches focused on the knowledge of the condition of the existing European building stock composition and energy performance. Based on statistical analysis, these studies aimed at obtaining benchmark values for homogenous group of buildings and at defining the most frequent building typologies. One of the most comprehensive overview of the EU-27 building stock is given in the BPIE report *Europe's buildings under the microscope* [4]. Based on the information drawn from the national statistical offices, it surveyed and compared the floor space area of residential and non-residential buildings, building typologies, characteristics and energy performance of current stock of the 27 Member States (plus Norway and Switzerland).

A rich literature is available for the description of the residential stock. At the European level, the TABULA [16] and EPISCOPE [17] projects outcomes represent nowadays a well-established reference point for studies aiming at modelling the residential stock [18,19]. Indeed, TABULA [16] created a harmonized structure for European building typologies and applied it to the thirteen project partner countries. Sets of model of residential reference buildings (from single houses to apartment blocks) were created for Germany, Greece, Slovenia, Italy, France, Ireland, Belgium, Poland, Austria, Bulgaria, Sweden, Czech Republic and Denmark. The obtained typologies were then further detailed and developed in the EPISCOPE project [17], where they were also exploited to define trends and scenarios for CO_2 emissions reductions. The understanding of the residential stock was deeply addressed at the national level as well. For instance, Dascalaki et al. [20] and Theodoridou et al. [21] examined and classified the Greek residential building stock, the former through sample buildings, the latter through statistical analysis. The Danish residential sector was modelled by Tommerup and Svensen [22]. The Italian residential stock was analyzed by Caldera et al. [23] and Fracastoro and Serraino [24] who proposed to correlate the residential space heating

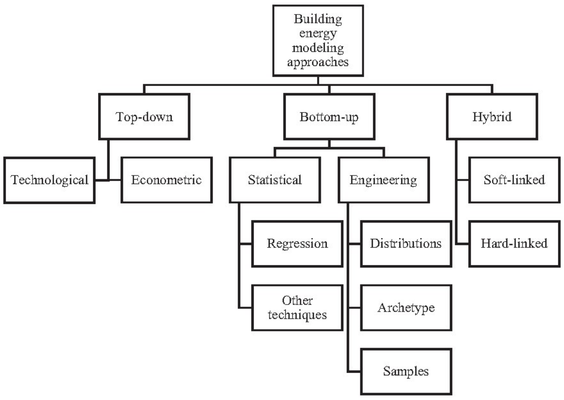

Fig. 1. Building energy modelling approaches.

consumption to the building stock feature, while Filogamo et al. [25] proposed a method to identify buildings representative of a large stock based on statistical data.

The deep understanding of the housing stock was a prolific ground for the development of prediction models of the energy demand of the residential sector [22,23,26]. Indeed, in their literature review, Hall and Buckley [11] detected residential sector as the second most quoted (behind transport) for energy models related academic literature. Critical reviews and comparisons among bottom-up residential models can be found in Kagvic et al. [15] and Martinez Soto and Jenstch [27].

On the opposite, European energy models related to the whole building stock, residential and non-residential, are currently very scarce and they use simplified input data [28]. A primary reason for this lack is that studies related to a comprehensive description of the non-residential stock are less frequent and do not cover all the diverse building typologies. Santamouris et al. [29] focused on the energy classification of school buildings in Greece. Using a large database on energy consumption of educational buildings, their energy performances were classified by employing a fuzzy clustering technique. A series of papers focused on the description of the hotel sector. Pieri et al. [30], based on the energy audit of 35 hotels, performed a multivariate analysis in order to cluster hotels buildings based on selected features (e.g. hotel size, annual primary energy use, star rating). For each cluster of hotels, the relevant differentiating features were hotel size, number of beds and primary energy consumption per guest-night. For each cluster the mean energy use and best case were identified and based on these findings an energy saving index was elaborated. Farrou et al. [31] presented a method to classify hotel buildings based on their electricity and oil consumption, aimed at the creation of benchmarks and reference values for this building sector, characterized by diverse sizes, operation and energy use. With equal aim, Boemi et al. [32] combined statistical data about the Greek hotel building stock, classified according to their localization features, with the audits of 50 selected hotels in order to identify sample hotels, typical and representative of the total stock. Gao and Malkawi [33] proposed a new method for benchmarking commercial buildings, based on the clustering concept, rather than on the most popular building type criteria. By analyzing a dataset of different type of commercial buildings, such as hotels, retail, offices, schools, the most critical features impacting energy consumption (e.g. area, equipment density, operation schedules) were defined through linear regression and they were used to create clusters of buildings. Upon clustering, the authors defined benchmark values for each cluster of buildings according to the centroid of the cluster.

Reasons for the discrepancy in knowledge between residential and non-residential stock mainly lay in the higher share of residential buildings in the EU building stock (75%) and the easier definition and comparison of residential building types. Indeed, the diversity in terms of typology within the non-residential sector is vast and with pronounced differences from country to country [4]. Further diversity emerges within each building category. Based on the services offered in each non-residential building, the energy consumption can vary widely. Indeed, most of non-residential building are multi-functional buildings where the main function is coupled with side activities (e.g. restaurant, conference hall, swimming pool). These activities, despite being complementary to the core function, represent an important share of the energy uses of these buildings and are often the characterizing elements, shaping, in real life, the business success of commercial buildings. Due to the high fragmentation of the multi-functional building stock, studies specifically dealing with multi-purpose buildings are rare and they typically aim at assessing the energy and performances of a well-defined case study [6–8].

A sort of formal permission to give the priority to the residential building stock can be spotted also in the relevant legal documents providing the frame for cost-optimal methodology implementation in EU Member States (MSs) [30,34]. Regulation 244/2012 [35] prescribes as compulsory the definition of one Reference Buildings for new buildings and at least two for existing buildings subject to major renovation for single- and multi-family residential buildings and for offices. For other non-residential buildings, if national specific minimum energy performance requirements do not exist (which is most often the case), MSs can derive them from a basic office RB. However, BPIE [4] estimated that the EU average specific energy consumption in the non-residential sector is 280 kWh/m^2 y (covering all end-uses), at least 40% higher than the equivalent value for the residential sector, with variations expected from country to country and from one building type to another. An oversimplification in the description of the non-residential building stock may dampen the understanding of the whole energy system and lead to unreliable long-term scenarios analysis.

In this sense, the US approach is more complete. With the aim of setting aggressive goals for energy efficiency improvements in buildings, the U.S. Department of Energy (DOE) promoted the use of bottom-up engineering models for the whole building stock. Huang and Brodick [36] calculated the overall energy use of the US building stock by examining the energy uses of 112 single-family, 66 multi-family housing and 481 commercial building. Detailed archetypes of U.S. commercial buildings are provided in [37]. 15 reference energy models for the most common commercial buildings (representing 65% of the total building stock energy consumption) were determined for 3 construction period (pre-1980; post 1980; new), across 16 locations representative of US climate zones.

2.3. Reference buildings in Europe

In Europe, the bottom-up engineering methods for modelling the building stock are popular [26,28,38,39] and they are the most preferred by policymakers. Particularly the use of archetypes was strongly promoted at the European level. Indeed, in the recast of the Energy Performance of Building Directive (EPBD recast) [40] and its accompanying guidelines [34], the EU Commission introduced the requirement for Member States to define Reference Buildings, as models based on a solid understanding of the current building stock and representative of the typical and average building typologies across Europe. Evidently, the EU definition of RB perfectly matches with that of archetypes provided by the building models-related literature.

The so-defined Reference Buildings are the starting point for the national applications of the EPBD recast [40], currently in force. As widely known, the EPDB recast asks to EU Member States (MS) to set minimum energy performance requirements for new buildings and major renovations with a view to achieving cost-optimal levels up to December 2020 and to achieving nearly Zero Energy (nZE) levels from January 2021 onwards. Reference Buildings are the objects on which hypothetic interventions are applied and evaluated through energy simulations. The energy end-uses accounted are the typical ones, i.e. heating, cooling, ventilation, hot water, lighting and – not compulsorily – appliances, used to maintain the indoor standard comfort condition. Indeed, since the energy performance of a building depends on the climatic indoor environmental quality targets set for it [41], it may be assumed that the typical energy use of a building depends on its typical comfort condition [42]. With this approach, the whole stock is considered as a set of "empty boxes" to which a rather uniform array of energy efficiency measures at the building level can be widely applied.

The objective, at the building scale, is to deliver representative calculation outputs, i.e. technical and economic opportunities, feasibilities and limits, in order to define the minimum energy performance requirements. On a bigger scale (urban, regional, national), RBs are exploited to create models for the stock characterization [18,43] and to define renovation tracks [5,37]. Indeed, the modelling approach related to archetypes is the most appropriate to define long term scenario analysis related to the energy performance of the built environment.

Despite the common guidelines [34], Member States have very different approaches in methodology and degree of detail when defining RBs, ranging from comprehensive catalogues of detailed RBs (Germany), passing through few reference buildings in the residential sector and adjusted use patterns for the non-residential sector (Netherlands, *Estonia*), to example Reference Buildings (Denmark) and down to not having RBs at all. The EU projects TABULA [16], EPISCOPE [17] and ASIEPI [44] contributed to the harmonization process. TABULA and EPISCOPE created a EU harmonized structure of residential building typologies. In ASIEPI project [44] the existing reference buildings for single family houses were collected for various countries, pointing out the architectural and calculation methods differences.

Theoretical proposals for a harmonized modelling of EU Reference Buildings can be found in [45] and [46]. Corgnati et al. [45], inspired by DOE RB models [37], defined 4 sub-sets of information to be collected for the definition of RB are listed (form; envelope; system; operation) and the method is applied for the definition of an existing Italian office RB. Brandão de Vasconcelos et al. [46] proposed and alternative method to collect data, grouping them into: configuration; constructive solutions and others. By applying their own RB definition method, they drafted a Portuguese multi-family residential Reference Building.

From the above overview, the preponderance of the application of this archetype-based modelling approach to the residential sector emerges, suggesting the necessity to adequately describe the non-residential sector as well. Given the need to better describe the whole EU building stock and to provide models for testing building renovation policies, this research is intended to give a contribution to the definition of a set of European non-residential Reference Buildings. These archetypes enable the calculation of energy benchmarks based on an idealized model of energy performance. Moreover, if well calibrated to the actual building stock, they are powerful tool to analyze and vary a wide range of factors that contribute to the energy use of non-residential buildings.

2.4. The hotel sector in Italy

Hotels are fitting examples of non-residential buildings where multiple services are offered to their users. In this view, this building category was selected for applying the methodology that this paper proposes. As a further justification to the selection, a long list of EU projects addressing the problem of the energy uses of the hotel sector can be put forward (e.g. CHOSE [47], HOTRES [48], RELACS [49], HES [50], neZEH [51]). These initiatives prove the growing attention that European Commission gave to this sector in the past decade. Indeed, hotels are energy intensive buildings with high potential in energy use reduction and, due to the number of clients they receive, they also have the potential to act as an example of energy responsibility for other industries, as well as for individuals [50].

In this context, the Italian hotel sector provides large room for application. With 34,000 structures, Italian hotels represent the 18% of the EU stock and they directly contribute 4% to the Italian Gross Domestic Product (GDP) [52]. Indeed, Italy ranked 5th among the preferred global tourism destination and 7th for tourism related incomes. [53]. The refurbishment of the hotel sector could further increase its positive impacts at economic and societal level (e.g. reducing emission, job creation, education of guests).

Despite the strategic importance of this sector, studies related to the energy characterization of the Italian hotel stock are rare and scattered. The Italian as well as the EU hotel market are characterized by high fragmentation concerning size, quality, occupation rate, services rendered, market development etc. [47]. As a consequence, the energy needs of hotels have a very wide range of variation, that is challenging to depict. CHOSE project [54] obtained, through audits, the average data of energy uses for a selected group of Italian 4-stars hotels, open all-year, with conference room, restaurant and laundry and an average dimension of 150 rooms. A survey on 4-5-stars hotels all around Italy, open all year, with an average dimension of 100 rooms provided information about the average electricity uses [55]. Beccali et al. [56] focused on the on Sicilian hotels' thermal and electrical energy consumption. Based on the description of the census data, sample Sicilian hotels where selected and audited in order to rank potential energy saving measures. A national report [57] presented results of building energy simulations of 2 reference hotels (3 stars and 48 rooms – 4 stars and 112 rooms), giving figures about reference energy consumption for heating, DHW, cooling and electricity for different hotel types in Northern, Central and Southern Italy. Table 1 summarizes the main numerical findings of the quoted studies, in terms of average energy consumption of the analyzed hotel stock.

The highlighted lack of a systematic approach towards the understanding of the Italian hotel stock from the energy perspective led the authors to further narrow the focus for the application of the multi-functional building modelling method. The modelling approach was applied to create an Italian Reference Hotel.

3. Method - Definition of a reference multi-functional building

This paper elects multi-functional buildings (mfBs) as a specific object of study, proposing a methodology for creating models of Reference multi-functional Buildings (RmfB). The method is based on 3 subsequent steps: 1) identification of the relevant energy uses of a mfB; 2) definition of relevant sub-categories of mfBs; 3) application of the RB modelling method to the selected sub-categories, to obtain a RmfB.

The process is graphically summarized in Fig. 2 and a detailed description of the steps is provided below.

3.1. Step 1 – Energy uses of a mfB

Multi-functional buildings represent an important share of the non-residential building stock, as they include all buildings hosting a wide range of activities with diverse energy patterns and intensities. The specific nature of mfBs requires a proper contextualization in order to be able to build realistic energy models. Indeed, in mfBs the energy uses intended to describe them as *a place to live*, i.e. energy uses to provide comfortable indoor conditions, are coupled with the energy uses related to the building as a *process*, i.e. to provide services. [9]. Particularly, while the energy uses related to maintaining comfort conditions are rather constant among different buildings, the energy use related to the services offered can vary broadly. In order to unify this dichotomous interpretation, the present paper propose to describe a mfB as a set of thermal zones and to classify these thermal zones based on the aim of their energy uses (*place to live* or *process*). Thermal zones where the main aim is to maintain standard indoor comfortable conditions (*place to live*), such as residential units, offices, meeting rooms, dining rooms, are referred to as "typical" functions, in line with the European definition of "typical energy use" of a building [41]. As recommended in EPBD recast [40], the energy uses considered

Table 1
Average energy uses of selected Italian hotel categories, based on literature findings. Note: (B) = Business hotel; (L) = Leisure hotel.

Hotel cat.	Macro clim. zone	Ref.	Source of energy [MWh/(room * a)]		End-uses [MWh/(room * a)]			
			Fuel	Electr.	Heat.	DHW	Cool.	Equip. & light.
1–2*	South	[56]	2.2	1.6	–			
3*	North	[57]	6	5	3 (B)	4.8 (B)	1.3 (B)	3.3 (B)
					1.8 (L)	3.8 (L)	2 (L)	3.2 (L)
	Centre	[57]	–		1.3 (B)	4.8 (B)	2 (B)	3.3 (B)
					1.8 (L)	3.8 (L)	2 (L)	3.2 (L)
	South	[56]	5.3	4.7	–			
		[57]	–		0.4	3.8	2.7	3.2
4* (#4/5*)	North	[54]	54.1	6.6	4.6	4.4	1.2	
		[57]	–		3.7 (B)	4.8 (B)	1.3 (B)	5.2 (B)
					2.1 (L)	3.8 (L)	1.9 (L)	5.1 (L)
		[55]#	–	7.7	–			
	Centre	[54]	25	9.7	4.1	4	2.9	
		[57]#	–		1.7	4.8	2	5.2
		[55]#	–	7.7				
	South	[56]	8.7	4.2	–			
		[57]	–		0.7	3.8	2.7	5.1
		[55]#	–	7.7	–			

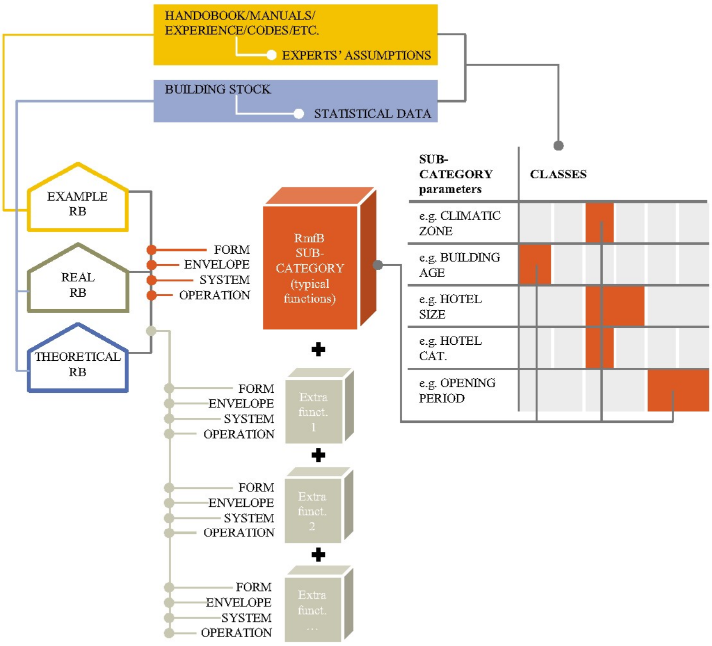

Fig. 2. Method for the selection of a Reference multi-functional Building and for its detailed description.

for the typical functions are heating, cooling, ventilation, hot water, lighting and appliances used to maintain the indoor standard comfort condition. These energy uses (with proper normalization) remain similar among different buildings.

Conversely, thermal zones where a specific service is offered to users (*process*), e.g. kitchen, laundry, swimming pool, gym, are the "extra" functions and their energy consumptions highly depend on the number and combination of services offered and on the service quality level. In these zones, the energy uses account for all the energy flows related to users' satisfaction, such as special comfort conditions (e.g. in a spa) and energy intensive appliances (e.g. in a kitchen).

Each multi-functional building is therefore interpreted as a combination of "typical" and "extra" functions, where typical energy uses are exploited to compare the standard energy performances of different mfBs and the extra energy uses are devoted to analyze their actual energy intensity and to compare the energy use of similar extra services. In line with this distinction, the method here proposed for the definition of a RmfB differentiates between typical and extra functions and related energy uses.

This approach is in contrast with EU dispositions, that prescribe minimum building energy requirements to be solely based on the typical energy use of Reference Buildings. These guidelines perfectly fit with the description of the residential stock. In residential buildings preserving the indoor environmental quality for occupants is the main goal of the building-plant systems, therefore energy uses for maintaining standard comfort conditions (defined by common EU standards [58]) are the proper variables to be considered in evaluating residential Reference Buildings' energy and economic performances. However, the "typical energy use" of a building is not enough to provide representative figures of energy use in non-residential RBs. For each of these RBs, the typical energy use should be coupled with additional energy uses related to extra functions.

In order to provide a concrete example of the proposed approach to the energy-related description of a multi-functional building, its application to a hotel building is here presented. In hotels, the typical functions common to all accommodation structures are the so-called *hosting functions*. They comprise all the thermal zones where standard comfort condition for guests and workers have to be maintained. These zones include guestrooms, offices, reception hall, lobby, bars, restaurants, meeting rooms, offices, reception, staff facilities, service rooms. Being these functions always present in a hotel and providing similar comfort levels throughout the whole building category, they can be identified as "typical". The extra functions, instead, account for the *additional services* offered to hotel's guests (e.g. swimming pool, sauna, fitness area, kitchen, laundry). Their presence entails a wide gap in the energy needs even among buildings with the same general classification, but also different market appreciation and economic success of the hotel as a business. Due to the high fragmentation of the accommodation building stock and the lack of disaggregated data, it is not possible to define typical presence or energy use of these services. Their relevance in a hotel total energy balance is evaluated by applying the basic principle of the superposition of effects.

The definition of a Reference multi-functional building requires the identification of the typical functions as the basis for drafting the model. Indeed, the model have to rely on the distinctive features representative of the building category itself. The extra functions are implemented in a second phase, as additional entities to the typical functions, in order to point out their role on the hotel total energy use.

3.2. Step 2 – Definition of mfB sub-categories

In case of very diverse building stock, as that of non-residential multi-functional buildings, EU guidelines [34] recommend sub-categorization of each building category, in view of providing typical average characteristics of representative sub-categories rather than meaningless one-fit-all information. Moreover, it is recommended for Reference Buildings to be defined for each sub-category.

For multi-functional buildings, the sub-categorization proposed in this paper take into account typical functions only, in order to detect common and uniform energy patterns. To this purpose, sub-categorization should be based on the most impacting factors influencing the typical energy use of a mfB.

In the followings, parameters for the sub-categorization of the hotel building stock are proposed as an example of application. Based on literature review, the most energy-influencing factors were selected. The classes related to each sub-category should be defined at national level, according to local dispositions, experts' evaluations and statistical distribution of these features across the national hotel buildings stock. Relevant categories for hotel buildings in terms of typical functions and their justifications are here given:

- Climatic area. Main physical parameter deeply influencing the energy use of all building types, it is suggested as sub-category at the EU level [34] and by the relevant literature related to the creation of benchmarks for the hotel stock [30–32].
- Building age. Physical parameter common to all building types, it is suggested as sub-categories in [34] as mirror of the geometry and the properties of the building plant-system.
- Hotel size. Physical parameter mentioned as subcategory in [34]. In the specific case of hotels, size is usually expressed in terms of number of beds. Pieri et al. [30] elected hotel size (both in terms of number of beds and floor area) as a significant variable is their analysis of the hotel stock and Boemi at al. [32], based on statistical data, defined typical hotels for different sizes (small, medium, large).
- Hotel category. Physical parameter specific for accommodation structures. The "stars" classification implies different minimum services offered to guests, which affect the energy consumption of the building. In their analysis of the Greek hotel stock, Pieri et al. [30] defined stars as a potential factor of differentiation. Beccali et al. [56] assumed the definition of classes of hotels based on their star classification as a preliminary step the analysis of the Sicilian building stock.
- Hotel opening period. Operational parameter related to the hosting functions that has the highest impact on hotels annual energy use. Indeed, Farrou et al. [31] differentiated between hotels with annual and seasonal operation, in their proposal of a hotel classification based on energy use data.

3.3. Step 3 – Creation of the RmfB

For each potential sub-category of mfB, the next step is the identification of the typical functions' detailed parameters, required to perform reliable energy calculations. At this stage, a RB modelling method is implemented and the RmfB is created. In line with the modelling approach of the DOE non-residential RB models, in this paper the method proposed by Corgnati et al. [45] was selected. The four sections of parameters and the included features are:

- Form. It includes: floor area, number of floors, floor height, orientation, shading, aspect ratio, façade area, window/wall ratio, and similar geometrical information.
- Envelope. It presents information about building construction technologies and materials along with their thermo-physical properties.
- System. Information about the heating and cooling systems, the ventilation system in place, systems for energy generation and production from renewables are given. Data such as HVAC systems type, components efficiency, control settings or lighting fixtures are included in this section.
- Operation. It lists the operational parameters affecting the energy use of the building, usually expressed through a set of schedules representing, for instance, building occupancy, lighting, equipment, heating and cooling set-points or ventilation rates.

Irrespective of the data grouping method chosen, the information can come from statistical analysis or from experts' assumptions. According to the sources available, for each sub-set of parameters different approaches may be used to create a RB [45]:

(1) Example Building, based on experts' assumptions and studies, when statistical data are not available.
(2) Real Building, existing building with the most typical building of a certain category, based on statistical analysis.
(3) Theoretical Building, virtual building with a composite of the most common features within a category of buildings.

For each extra function added to the baseline Reference Building (where only typical functions are accounted), the same modelling method is implemented. Data about form, envelope, system and operation are gathered from experts, statistics or field monitoring, according to availability, and they are used to model these functions as additional elements. In this way, the relevance of extra energy uses with the respect to the typical one is assessed and the evaluation of different combinations of functions is possible. A wide range of multi-functional buildings can be represented by combining the same "typical functions" model with different "extra-functions" ones.

3.4. Large scale application perspectives

Scaling-up the applicability of the proposed methodology is a necessary step towards the fulfilment of the most recent EU goals. A more realistic modelling of such energy-intensive buildings would entail more effective energy efficiency strategies for the whole building stock retrofit.

Transposing the proposed modelling principle at a larger scale (e.g. urban, district, etc.) would entail the classification of the energy performances of non-residential buildings based on parameters that overcome the traditional classification in building categories. Indeed, sub-categories of multi-functional buildings formally categorized in different typologies (e.g. educational buildings, offices, shopping malls) may present similar energy patterns in terms of typical energy use. Transversal sub-categories of mfBs could therefore be created, with a categorization based on the comfort level they are supposed to provide to their occupants, their construction period, their location, etc. In general terms, a single benchmark value for typical energy use could be used to coherently represent and evaluate the energy performance of a wide range of non-residential buildings with homogenous characteristics.

At this scale, extra-functions can be considered as free-standing elements, added to the model on a statistical basis, in order to represent the building stock object of analysis.

Fig. 3 depicts the envisaged application of the model method at a large scale and it complements the scheme provided in Fig. 2.

4. Results

4.1. An Italian Reference Hotel

The methodology proposed above was applied at the building level with the aim of providing a systematic approach to the definition of Reference Hotels (RH) in the Italian context. The created model is intended to facilitate the characterization of this highly fragmented building category and lo enlarge the "library" of Italian Reference Buildings, where, at present, only residential and office buildings have detailed models [45,59].

Classes of parameters for the sub-categorization of the building stock in terms of its hosting functions (i.e. typical functions) are presented in Table 2. Choices for the classification are based both on experts' assumptions and on statistical data, as shown in the following:

- Climatic area, from experts' assumption. Italy is formally divided in 6 climate zones, classified from A to F according the increasing Heating Degree Days (HDD). Nonetheless, in order to avoid excessive fragmentation, in this study the considered climatic zones refer to those used for Italian building typologies developed in the framework of TABULA project [60].
- Building age, from experts' assumption. The division in classes of the existing building stock is taken from the Italian outcomes of TABULA project [60]. Despite TABULA project only deals with residential buildings, the Italian existing hotel stock is considered by authors very similar to the residential building stock in terms of geometry and construction typology, mirrored by each construction age.
- Hotel size, from statistical classification. In the specific case of Italian hotels, size classes are provided, in terms of number of guestrooms, by the national statistics institute [61].
- Hotel category, from national codes. In Italy hotels are classified according to "stars". As required by the Italian Decree [62], "stars" classification implies different minimum services to offer to guests.
- Hotel opening period, from experts' assumption based on statistics. This classification is suggested by [57], in which an Italian hotel market segmentation analysis pointed out the most common opening period options.

The study focused on the Italian Middle climatic zone. In this zone a medium size, 3-stars hotel, open all year and built between 1921–1945 was selected as the subcategory of Reference Hotel to be developed, because:

- in the Italian middle climatic zone (e.g. Turin, Milan), urban hotels devoted to business and cultural tourism - therefore open all year - are representative of an important share of the accommodation market [57];
- 3-stars hotels represent the highest share of businesses (45%) and beds (43%) of the Italian stock [61];
- medium size hotels, more common in the urban contexts, are the 42% of businesses and 56% of guests' beds of the Italian hotel offer [61];
- hotel businesses increased constantly from 1930 onwards [63]. Hotels built between 1921 and1945 are taken as example of early stage buildings asking for deep retrofit actions.

The identified Reference Hotel sub-category was then developed in terms of its detailed parameters. References for each section are here detailed:

- Form. Statistical information about the hotel building stock in terms of size, accommodation capacity, category and location were taken from the Italian statistic institute [61]. Based on these data, an existing building representing the average stock for the chosen hotel subcategory was selected. Due to a lack of information about other dimensional/geometrical features of the hotel stock, the choice of a real hotel building, elected by statistics as representative of a specific category, was the only possibility to have enough detailed data to build a simulation model.
- Envelope. Information were derived from the Italian Building Typology brochure [60], based on the review of the real building envelope features. For the Italian context it is reasonable to assume construction techniques adopted for hotel buildings to

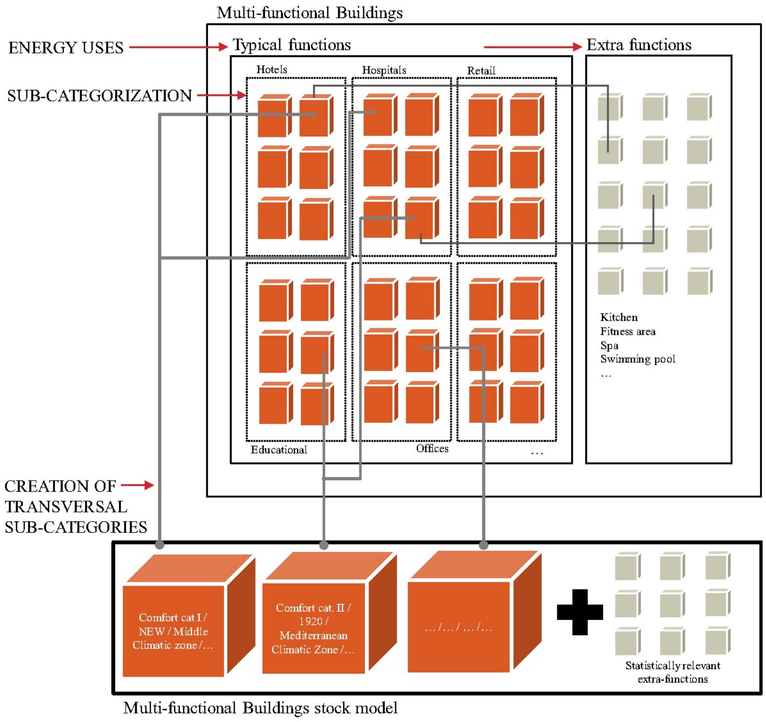

Fig. 3. Perspectives of large scale application of the proposed modelling methodology.

Table 2
Sub-categories and related classes for the definition a Reference Hotel.

Sub-category	Classes							
Climatic area	Alpine (HDD < 3000)			Middle (HDD 2100–3000)			Mediterranean (HDD > 2100)	
Building age	… – 1900	1901–1920	1921–1945	1946–1960	1961–1975	1976–1990	1991–2005	2006 – …
Hotel size	Small (⩽24 guestrooms)			Medium (25–99 guestrooms)			Large (⩾100 guestrooms)	
Hotel category	1*	2*		3*	4*		5*	
Opening period	All year			Summer			Winter & summer	

be very similar to those for residential buildings, specific object of [60]. Indeed, the selected real building envelope characteristics (not detailed enough to be used) are very similar to the features proposed by Ballarini et al. [60].

- System. Specific information was derived from experts' assumptions used in TABULA project [27] for heating and from field research findings presented in [57] for cooling.
- Operation. According to the availability, operation schedules and peak values were derived from UNI 10339 (national standard) [64], EN 15232 (EU standard) [65] and DOE "Small Hotel" Reference Building [37], obtained from methodologies (2) and (3) applied to the US context. National data were preferred and integrated with European and US standard only in case of missing information. In order to comply with local requirements, Heating and Cooling operative temperature set-points were taken from EN15251 [58], ventilation rates from UNI 10339 [64].

With regard to extra services, kitchen and fitness area were implemented as "additional entities" to the Reference Hotel hosting functions and integrated in the internal layout of the hotel. The detailed parameters were collected following the same approaches used for the hosting functions, with the exception of the "operation" section, in which the schedules proposed by DOE

[37] were adapted to the Italian hotel context based on hotel sector experts' assumptions.

Tables 3–6 summarize the obtained RH main features respectively for form, envelope, system and operation. In Figs. 4–6, heating set-point schedules and lighting and equipment schedules respectively exemplify the different indoor conditions of guestrooms (thermal zone selected as representative of the hosting function), kitchen and fitness area. In Fig. 7 the internal layout of the whole hotel is displayed distinguishing between hosting and extra functions.

4.2. Energy use of the RH

Once the Reference Hotel was defined, the model was built in Energy Plus by implementing the detailed information previously gathered about form, envelope, system and operation. For the purpose of the simulation, the RH was located in Turin (HDD = 2617), representative of the Italian Middle Climatic Zone, and an annual simulation was run.

Outcomes were reported for typical functions (hosting functions) and extra functions (extra services) of the building. Results

Table 3
Italian Reference Hotel's main characteristics regarding form.

Building form	Unit	Data	Data source
Gross area	m^2	2117	Existing building representing the sub-category's average hotels stock
Gross conditioned area	m^2	1700	
Average gross area/floor	m^2	423	
Number of floors	–	5 (4 + basement)	
Orientation	–	S-N	
Aspect ratio (S/V)	–	0.28	
Floor height (clear height + ceiling)	m	3.5	
Number of façades	–	3	
Façades total area	m^2	1275	
Opaque façades area	m^2	1059	
Window/Wall ratio	–	0.17	
Number of guestrooms	–	49	
Average guestrooms area	m^2	21	
Number of beds	–	95	

Table 4
Italian Reference Hotel's main characteristics regarding envelope.

Building envelope	Data	U [W/m² K]	Data source
External walls construction	Hollow wall brick masonry	1.1	[60], selection based on real building site visit
	Hollow brick masonry, low insulation	0.8	[60], selection based on real building site visit
Internal walls construction	Hollow brick wall	2.3	Real building
Ground floor construction	Concrete floor on soil	2.0	[60], selection based on real building site visit
Floors construction	Floor with reinforced brick-concrete slab	1.65	[60], selection based on real building site visit
Roof construction	Floor with reinforced brick-concrete slab, medium insulation	0.7	[60], selection based on real building site visit
Windows	Single glass wood frame (g = 0.85)	4.9 (U_w)	[60], selection based on real building site visit
	Single glass, metal frame without thermal break (g = 0.85)	5.7 (U_w)	[60], selection based on real building site visit
Doors	Glass and metal doors thermally improved (g = 0.75)	3.8 (U_w)	[60], selection based on real building site visit

Table 5
Italian Reference Hotel's main characteristics regarding envelope.

Building system	Data	Data source
Ventilation	Natural	[60], selection based on real building site visit
Heating system	Centralized, with radiators	[60], selection based on real building site visit
Heating energy source	Natural gas	[57], confirmed by the real building site visit
Cooling system	Centralized, with split	[57], confirmed by the real building site visit

Table 6
Italian Reference Hotel's main characteristics regarding operation.

Building operation	Data		Data source
Heating set-point	21	Guestrooms, toilettes, hall, dining room, offices, reception, kitchen	EN15251[58]
	18	Fitness area, service rooms, circulation areas	
Cooling set-point	25.5	Guestrooms, toilettes, hall, dining room, offices, reception, fitness area, kitchen	EN15251[58]
	–	Service rooms, circulation areas	
Air change per hour	0.011 [$m^3/(s * pers.)$]	Guestrooms, hall, dining room, offices, reception, service rooms, circulation areas	UNI 10339:2005 [64]
	8 [h^{-1}]	Toilettes	
	0.0165 [$m^3/(s * pers.)$]	Fitness area	
	0.0165 [$m^3/(s * m^2)$]	Kitchen	

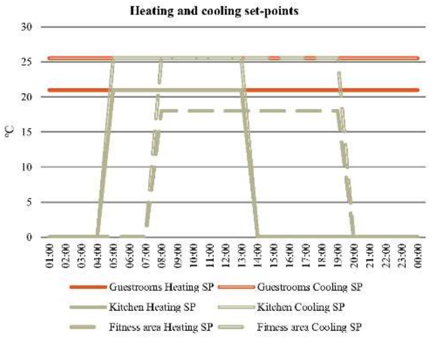

Fig. 4. Schedules for heating and cooling set-points in guestrooms, kitchen and fitness area of the Reference Hotel.

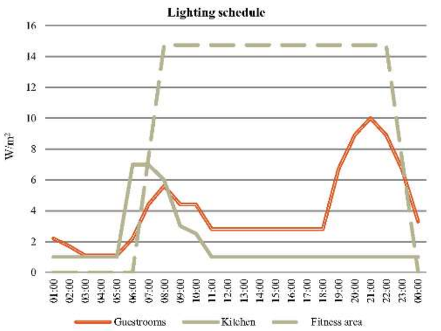

Fig. 5. Schedules for the use of lighting in guestrooms, kitchen and fitness area of the Reference Hotel.

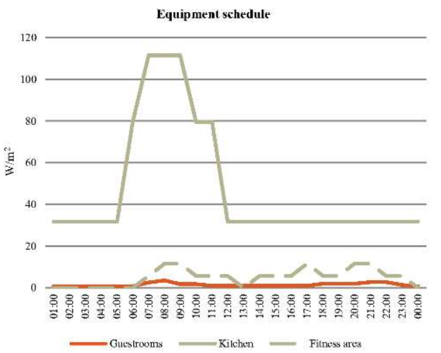

Fig. 6. Schedules for the use of lighting and equipment in guestrooms, kitchen and fitness area of the Reference Hotel.

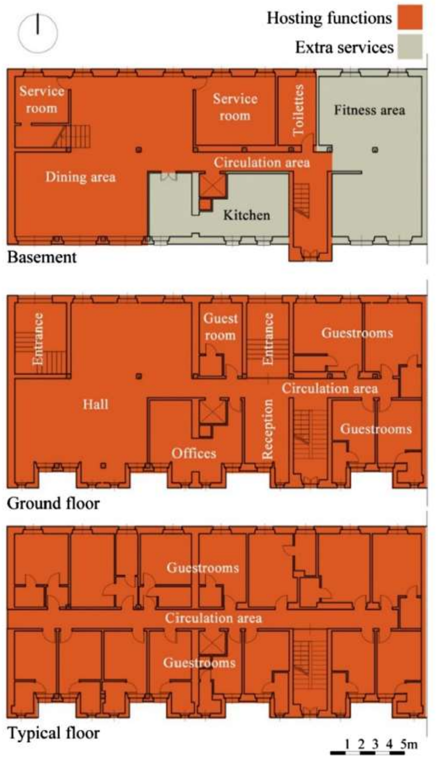

Fig. 7. Reference Hotel's internal layout for basement, ground floor and typical floor.

were expressed both in terms of delivered and of primary energy, for which Italian Primary energy conversion factors were applied (1,05 for Natural Gas, 2,42 for Grid Electricity). Results are normalized by floor area and by guestrooms number.

The hotel delivered and primary energy use are reported in Table 7 with regard to its end-uses and in Table 8 as a comparison to findings presented in Table 2.

5. Discussion

In view of the development of long term long carbon goals related to the built environment, the definition of non-residential, multi-functional Reference Buildings is a necessary step for a robust understanding of the existing building stock. Indeed, archetypes (i.e. RB) are the base elements of most of the energy models of the EU building stock. However, the available methodologies for the definition of RBs according to EU dispositions do not allow a realistic depiction the complexity of these building typologies. Multi-functional buildings include a broad number of non-residential buildings, hosting different activities

Table 7
Delivered (DE) and Primary Energy (PE) use of the Italian existing RH for its functions.

Function		Whole hotel			Hosting functions			Fitness area			Kitchen		
Share of the whole PE use [%]		100			81			6			13		
Energy		DE	PE		DE	PE		DE	PE		DE	PE	
End-uses [kWh/m^2 a]	Light.	45	110	33%	35	84	36%	86	208	49%	16	40	2%
	Equip.	31	76	23%	16	38	17%	44	107	25%	427	1033	61%
	Fans & pumps	8	20	6%	6	15	6%	6	15	4%	36	87	5%
	Cool.	20	48	14%	16	38	16%	18	44	10%	29	70	4%
	Heat. & DHW	77	81	24%	54	57	24%	50	53	12%	452	475	28%
	Tot.	182	335	100%	126	232	100%	205	427	100%	960	1704	100%

Table 8
Delivered Energy of the RH (whole hotel), sorted by source of energy and end-uses. To be compared with Table 2.

Hotel cat.	Macro clim. zone	Ref.	Source of energy [MWh/(room * a)]		End-uses [MWh/(room * a)]			
			Fuel	Electr.	Heat.	DHW	Cool.	Equip. & light.
3 stars	North	Simul.	2.7	3.6	2.7		0.7	3

under the same roof. The present study proposes a new method to face this issue. The first step of the new methodology requires to detect and distinguish between typical and extra energy uses of multi-functional buildings and to take both into account by superposition of effects. With this approach, typical values related to functions with homogeneous energy requirements (i.e. the typical energy use) are obtained, together with energy use patterns of extra services. These "extra functions" models can be then added to the "typical functions" model in different combinations. As a second step, the paper recommends to define sub-categories of multi-functional buildings based on the features of their typical functions only, in order to create homogenous and widely applicable models. Additionally, the focus on typical functions allows the coherent interpretation of the EU requirements in terms of end-uses accounted in RBs [40]. These models will be then complemented with the extra-service ones according to the single modeler's needs. While the distinction between typical and extra energy uses is an issues that can be solved at the theoretical level (i.e. applicable to all contexts), the proposed approach for sub-categorization need to be grounded in the reality of the building stock under investigation. Among the several parameters descriptive of a building category, those with the highest impact on the variation of energy use of the selected stock have to be considered for sub-categorization. Each energy impacting parameter must be classified according to experts' assumption and/or national disposition and/or statistical analysis. Once the energy uses and sub-categorization issues are solved, the third step of the proposed methodology follows a well-established modelling procedure based on archetypes definition. The so-defined RmfB can be used as it is for the implementation of the cost-optimal methodology, as required in EPBD recast, or it can be inserted as input data in bottom-up engineering models of the whole building stock. Indeed, archetypes are the most suitable tools to test the impact of new technologies on long term building stock energy scenarios.

Multi-functional buildings are usually grouped in categories based on the building type (e.g. hotel, hospitals, educational buildings, retail, offices, etc.). As buildings within each category have in fact very different features and functions, the present paper proposes to by-pass this classification through the application of the above mentioned steps. Indeed, a large scale application of the sub-categorization process, based on the typical functions of mfBs, would lead to the creation of models mirroring homogenous transversal building categories. MfBs could be classified based on their most energy intensive features rather than relying on the traditional building-type categorization. Therefore, the same goal elicited by Gao and Malkawi [33], i.e. to obtain trans-category benchmark values for non-residential buildings, is here pursued with an archetype-based modelling approach, more common at EU Member States level. In this view, higher education and office buildings may use the same benchmark values for typical energy uses, while luxury hotels and hospitals energy evaluation may refer to a different (higher) reference value. The here proposed method has the further advantage of enabling the analysis of the effects that selected features may have on the created homogenous mfBs classes. Therefore, these archetypes could be exploited at national and European level to build realistic projections and strategies for energy efficiency of the building stock, while reducing the modelling effort (i.e. reducing the number of archetypes needed).

The proposed systematic distinctions between typical and extra functions would also entail the creation of a library of energy patterns and benchmarks for energy intensive activities, as the extra functions are. These figures, usually took over the overall energy use of the buildings in which extra functions are placed, could provide new insights on possible targeted strategies to reduce their energy consumptions. Additionally, as the "library" of benchmark values for extra-functions grows, they could become object of further categorization, based on the quality of the service offered, so that details could be added to the energy models both at the building and at the district scale.

It may be summarized that the major novelty that this paper intends to bring in the topic of energy-related building modelling refers to a change of perspective. At present, non-residential buildings are generally modelled with a low level of detail and/or referring to the building as a whole. Due to the vast variations in the non-residential stock features, this descriptive approach has two main drawbacks. On one side, the use of few representative buildings to depict the whole stock do not provide realistic building stock models and energy efficiency perspectives. For instance, using an office RB to derive minimum energy performance requirements of the whole non-residential stock (as European Commission suggests [35]) can lead to unfeasible minimum energy performance requirements. On the other side, the effort to cluster multi-functional buildings of the same categories and with comparable features may lead to a very fragmented picture of the non-residential stock, impossible to summarize in general figures and therefore hard to study in terms of energy/carbon reduction strategies. For instance, despite studies were conducted for the Italian hotel sector energy uses [54–57], their results cannot be compared due to the different features of each analyzed cluster of hotels. By adopting the approach proposed in this paper, homogenous transversal macro-categories of non-residential buildings can be created for their typical functions. Buildings with equal comfort requirements may be compared to equal benchmark values for evaluating their present and desired energy performance and they can be consistently implemented in building stock energy models (in terms of typical functions). In this framework, extra services are additional entities to be added for refining the energy model. At the building scale, extra-functions are included to evaluate the energy performance of a specific case study. At a larger scale (district/city), extra-function can be added on a statistical basis, representing the stock object of analysis.

As a test application at the building scale, the drafted method was applied to the definition of an Italian Reference Hotel. The RH sub-category was defined following procedures suggested by literature and based both on literature and observed data. The implementation made evident the main limit of the bottom-up approach to building energy modelling, the scarcity of data. A lack of statistical information about the hotel building stock drove the authors to the definition of rather arbitrary data about the RH, especially dealing with its geometry. The very low level and blurry information about the non-residential building stock are a major problem highlighted in major studies [4,5] and it cannot be solved by a single research as the present one. In this paper, once the sub-category of reference hotel was selected according to statics, the geometry and main features of an existing building mirroring the sub-category main features were used. The obtained Reference Hotel model contributes to enrich the existing collection of RBs describing the Italian building stock.

As a final step, a dynamic energy simulation was run in Energy Plus, with the aim of obtaining potential benchmark values for the hotel sub-category object of the analysis. Dealing with the energy use of the RH, remarks are two-sided. On one hand, the analysis of the typical and extra energy uses of the RH highlighted how relevant the latter are in the evaluation of the overall energy consumptions. Indeed, the extra functions simulated for the RH, despite their small relevance in terms of floor area (6%) and the low profile offered services (fitness area with gym equipment and kitchen serving breakfast only), accounts for approximately 20% of the whole building primary energy use, with specific primary energy consumption 6 times higher than the one for hosting functions for the kitchen and 84% for fitness area

On the other hand, the simulated results can be compared with findings of studies dealing with the same sub-category of hotels (Tables 2 and 8). The comparison highlights how difficult it is to define robust benchmarks for such a diverse building category at the present stage. Particularly, it is worth noting that all figures provided in Table 1 take into account all the functions of the hotels object of analysis. There is no detail about which extra services were included in the measured/simulated/analyzed energy consumptions. A distinction between typical and extra energy use could allow a better informed comparison among energy performances of different hotels and the definition of common refurbishment strategies. Building on these considerations, the RH model also contributes to a more informed characterization of the hotel stock.

6. Conclusions

Energy models of the EU building stock suffer from an incomplete understanding of the residential and non-residential building stock. While the residential building sector is described at the sector scale through different types of energy models and at the detailed scale through a series of archetypes, not much material is available for the non-residential counterpart.

As a contribution to fill this gap, this paper proposed a method to define Reference multi-functional Buildings for Europe. Multi-functional buildings represent a large sample of the non-residential building stock, whose various energy behaviors still require systematization. In this study, a method to depict the energy use of this building category at the building and district scale is presented, based on the distinction between typical and extra functions of a mfB. In this view, typical functions and the related energy uses are used to define the baseline archetype, while extra energy uses are added as flanking elements for the formation of multiple combinations of "typical + extra" functions.

The practical application of the methodology to the creation of a model of Reference Hotel for Italy highlighted the modelling issues that need to be addressed and suggested how to do it. Moreover, the defined Italian Reference Hotel can directly constitute a precious object on which retrofit measures can be tested in order to support national tourism and energy efficiency policies.

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Paper III

An existing best practice of nearly Zero Energy Hotel

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Figure 1. The first neZEH selected showcase: the Boutiquehotel Stadthalle in Vienna.

An existing best practice of nearly Zero Energy Hotel

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The paper presents the design concept and the energy consumptions of one of the few nearly zero energy city hotels in Europe, the Boutiquehotel Stadthalle in Vienna. The provided information resulted from meetings and questionnaires to the hotel, which was interviewed as best practice in the neZEH project.

Keywords: neZEH, nZEB, hotel, refurbishment project, sustainable design.

Showcasing existing best practices of nearly Zero Energy Hotels is one of the activities undertaken by REHVA as a partner of the IEE founded project neZEH*. Aim of this task is to provide hoteliers with the direct evidence that the

* **Nearly Zero Energy Hotels (neZEH)** is a 3-years long project supported by the Intelligent Energy Europe (IEE) program started in April 2013, involving a consortium of 7 European Countries (Croatia, France, Greece, Italy, Romania, Spain, Sweden) and 10 partners. The project aims at accelerating the refurbishment rate of existing buildings into nZEB in the hospitality sector and promoting the front runners. Focusing particularly on the SME hotels. http://www.nezeh.eu/

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nearly zero energy level is an achievable and profitable target for hotels.

To show to potential pilot project's initiators a complete overview of the best practices refurbishment process, information concerning both the economic and technical features are asked to the showcases, structured as a questionnaire for the technical and quantitative questions and as an interview for economical and qualitative aspects.

The first hotel selected as a showcase was the Boutiquehotel Stadthalle in Vienna (**Figure 1**) and the derived information are reported in the following paper. In this hotel the nZEB level is reached in the newly built "passive building", which became the world's first example of nearly zero energy city hotel.

The Hotel

Boutiquehotel Stadthalle is a three star hotel in Vienna, which became the first city hotel with a nearly zero energy balance thanks to its manager's strong commitment to environmental issues. The whole structure is formed by an apartment building of the beginning of 19th century and a newly built passive building. The hotel renovation process began in 2001, when Michaela Reitterer, current owner and manager, bought the 19th century hotel building and started to refurbish it. To comply with Ms Reitterer higher goals, in 2009, new works started to couple the renovated existing building with the new passive house, a nearly zero energy building, which was completed by the beginning of 2010. The additional building's installed technologies allowed it to reach a nearly zero energy balance.

The hotel has 79 guestrooms in total, 41 in the old building and 38 in the passive house, and does not offer extra facilities apart from a lounge bar. In accordance with what was defined as "typical energy use of a hotel" in the neZEH project, the latter aspect allows to consider all the energy consumptions of the Boutiquehotel Stadthalle in the nearly zero energy balance.

Table 1 displays the main data about the hotel.

The energy system

Different energy systems are installed in the "old" building and the passive house. While the refurbished 19th century building mainly uses district heating and has no cooling and active ventilation systems, the new section is equipped with a groundwater heat pump for heating and cooling, used for the concrete core activation, and with controlled air room ventilation (only ventilation, no air conditioning).

An in-house well serves as cooling source and provides groundwater to the heat pump, powered by a 13 kWpeak photovoltaic system (93 m²). In addition, 130 m² of solar thermal panels are used to produce domestic hot water for the whole hotel, as well as to pre-heat the fresh air through the ventilation system, which achieves over 90% heat recovery, as conceptually schematized in **Figure 2**.

Table 1. Hotel's main information.

Name	Boutiquehotel Stadthalle
Location	Hackengasse 20, Wien
Type of hotel	Urban
Owner	Michaela Reitterer
Floor area	2 271 m²
Floors	4 (existing building) – 5 (passive house)
Guest rooms area	1 316 m²
Guest rooms	79 (41 in existing building + 38 in passive house)
Guest beds	156
Offered facilities	Lounge bar
Total refurbishment costs	5 200.000 € approx.
Refurbishment cost	2 290 €/m² approx.

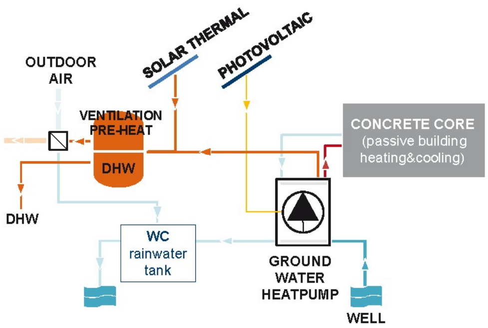

Figure 2. Conceptual scheme of the heating&cooling system and of the domestic hot water production.

The electricity needs for auxiliary systems, appliances and lighting not covered by the PV plant are currently supplied by the electricity grid, but 3 wind turbines are waiting for the permission of authorities for being installed on the building roof.

The hotel energy system is summarized in **Figure 3**.

The building plants are managed by a Building Automation and Control System (BACS): programmable automation controllers help maintaining the right balance between guest comfort and energy savings by monitoring and enabling the regulation of heating and ventilation based on actual demand or pre-defined schedules. The system also controls and monitors the concrete core activation, water heating, the solar panel system, buffer management and the groundwater heat pump.

The energy consumptions

The amount of measured delivered energy in the past three years by the Boutiquehotel Stadthalle is reported in **Table 2.**

To obtain primary energy, the proper primary energy factors are applied to the average yearly heat and electricity consumptions. The European non-renewable primary energy factors set by the latest version of standard FprEN15603:2014 are used: 1.30 for district heating, 2.30 for grid electricity. The obtained primary energy performance for the whole hotel (existing building and passive building) is shown in **Table 3**. The energy factor for the passive building, taking only electricity from the energy grid, is derived by applying a factor taking into account the different dimensions (number of rooms) of the old and the new constructions. With these premises, the calculated primary

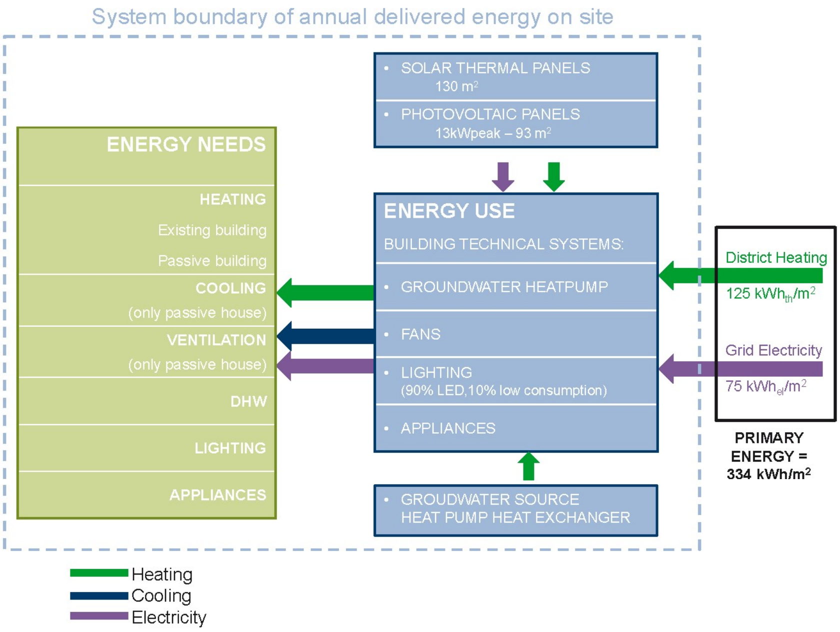

Figure 3. Scheme of the Boutiquehotel Stadthalle energy system.

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Table 2. Energy delivered to the building in 2010, 2011, 2012.

		Amount of energy use				Type of energy use									
		Total (0*+P**)		0*	P**	Heating		Ventilation		DHW		Lighting		Appliances	
Source	Year	kWh_{th}	kWh_{el}	%	%	0*	P**	0*	P**	0*	P**	0*	P**	0*	P**
District heating	2010	301.700		100 approx.	0 approx.	x				x					
	2011	263.100				x				x					
	2012	287.300				x				x					
Electricity grid	2010		170.200	65 approx.	35 approx.		x		x			x	x	x	x
	2011		159.500				x		x			x	x	x	x
	2012		177.100				x		x			x	x	x	x

*0 = old building **P= passive building

Table 3. Primary energy factor calculation for Boutiquehotel Stadthalle.

	Average yearly consumption		Non-renewable primary energy factor	Primary energy		Primary energy for heating, cooling, domestic hot water, HVAC aux, lighting	
				Whole hotel	Passive building	Whole hotel	Passive building
Source	kWh	kWh/m^2	–	kWh/m^2y		kWh/m^2y	
District Heating	284.033	125	1.3	163	0	163	
Grid Electricity	168.933	74	2.3	171	124	155	108
			Total	**334**	**124**	**318**	**108**

energy consumption of the passive building only is approximately 124 kWh/m^2y.

The gap in primary energy factors obtained for the whole building and for the passive building only reflects the different level of retrofit actions undertaken. In the passive house, where the goal set from the very beginning of the design phase was the zero-energy balance, the primary energy use including energy uses for heating, cooling, domestic hot water, HVAC aux and lighting, 108 kWh/m^2y, is in line with the reference value defined in the context of the neZEH project for Western Europe countries (zone 3 in **Table 4**), presented in REHVA Journal January issue. The primary energy use for the listed energy uses was derived by reducing the total primary energy of the appliances contribution (7 kWh/m^2 weighted by the primary energy factor).

Other sustainable features

The energy systems of the hotel are only part of the sustainable strategy adopted by the hotel, which strives to contribute to lower the environmental impact of the tourism business by implementing a wide range of measures.

Lighting. In order to reduce the hotel lighting power use, the 90% of the light sources are LED and the remaining 10% are low consumption bulbs. Moreover,

Table 4. Summary of the requirements for nearly zero energy hotels in Europe proposed by neZEH.

Zone	EP [kWh/m^2*y]	Energy uses
Zone 1	55	Heating, cooling, domestic hot water, HVAC aux, lighting
Zone 2	60	
Zone 3	95	
Zone 4	115	

lighting is automatically controlled by sensors in public spaces, while in guest rooms lighting is governed by the room badge presence in the dedicated fold.

Water. Water saving measures were undertaken from the very beginning of the renovation process, in 2001, when cisterns were installed to store rainwater and use it for toilets and the garden. Additional water savings methods were implemented in the new passive building, in which also the cold well-water is used instead of the rainwater to flush toilets.

Food. Despite being breakfast the only meal served at the hotel, the food policy undertaken by the hotel plays an important role in the holistic green vision of the hotel manager: the products served are either local or organic, or both local and organic.

Transport. In the effort of promoting the use of low emissions means of transport, the hotel provides a 10% discount to guests coming by train or bike, a free bicicle garage and free of charge recharge for guests' electric vehicles.

Education. Accordingly with the strong motivation and environmental concerns of the hotel manager, the education of guests is among the main goals pursued. The hotel provides to guests an example of how it is possible to have a zero energy building by informing them directly in their rooms: green points with explanation of the adopted green solutions are placed next to the corresponding point of use. Moreover, to check the indoor environmental quality level in a nZEB, "test sleeping" are arranged for interested parties in the passive house. Beside the education for guests, training courses are organized for staff members.

Waste management. A strict waste prevention (e.g. biodegradable cleaning supplies) and separation policy is implemented in the hotel and recycled fabrics are used in guestrooms.

Certifications. The hotel obtained the EU-Ecolabel certification in 2007, before the construction of the new passive building. Together with a few other hotels in German speaking countries, it is now founder of the Sleep Green Hotels network.

The economical side

Investment. Achieving the nZEB status took a significant financial effort: a reckoning of the investment costs, provided by the hotel manager and owner during the interview, highlighted that the total cost of the intervention from 2008 to 2010 exceeded 5 million euros. The first measures undertaken for achieving energy efficiency in the existing building accounted for more than 1 million euros, while the second part of the project, the passive house, cost approximately 4.2 million euros.

In this case, however, it must be highlighted that the consistent investment is not merely related to the energy retrofit, but also to the additional costs entailed by providing a sustainable and high quality indoor environment to guests (e.g. factors related to the hotel interior design).

Because of the financial crash of 2008, the extension of the hotel with the construction of the passive house did not receive any finance from Austrian banks except the furniture which was by the Austrian Tourism bank. The renovation was financed through a lease–back scheme according to which the hotel is going to be purchased back by the manager/owner.

Benefits. Despite the considerable risk assumed, the manager's choices were successful. Even if the Return of Investment was not a considered economic index by Ms. Reitterer, whose main purpose was to put in practice her green believes, her commitment proved to be not only a way to reduce the hotel operation costs, but also a choice appreciated by the market. Even if not providing figures, the manager affirmed that the return of investment came back faster than expected. In fact reaching the nZEB status, complementary with the other green actions engaged, entailed on the one side a lot of free visibility and media exposure, and on the other side opened the doors to a completely new target of guests and to a special market sector, enabling the hotel to keep both high room rates and high and constant occupancy rates (average yearly occupancy rate of 82% in 2012).

Conclusions

Achieving the nearly zero energy status in the Boutiquehotel Stadthalle was a result obtained by its manager and owner when the recast of the Energy Performance of Buildings Directive was not even in place. It required strong motivation and consistent economical efforts, very far from the cost-optimal level of energy requirements nowadays suggested by the EBPD recast. Nevertheless it proved to be a successful strategy, both in terms of achieved energy performance and of market appreciation. The Hotel Stadthalle became the first example of nearly zero energy urban hotel, with a primary energy factor of 108 kWh/m^{2}y in the passive building, which is in line with the preliminary benchmarks for hotels primary energy use defined by the neZEH project. ■

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Paper IV

Nearly Zero Energy hotels

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Nearly Zero Energy hotels

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Keywords: hotels, nZEB, neZEH, energy use, refurbishment

The focus of the European project neZEH on hotels raised the question of how to define requirements for nearly Zero Energy Buildings when complex buildings are concerned. This paper presents the first steps made to enter this topic, including a review of the existing hotel buildings stock energy performances.

Introduction

According to the UNWTO-UNEP study (2008) [1] tourism contributes around 5% to global CO_2 emissions, out of which hotels and other types of accommodation account for 1%.

This comparatively small footprint is nevertheless important in the EU strategies to achieve the 2020 goals, as proved by the projects dealing with the hospitality sector promoted by the IEE in the last years, such as HES[1] and RELACS[2], and neZEH project which started in spring 2013.

The most recent goal to be achieved within the hotel sector goes beyond the generic increase in the energy efficiency and use of renewables: the neZEH project aims at retrofitting existing hotels to achieve the nearly zero energy level.

Among the several building uses, focusing on the existing building stock of the hotel sector could be an asset for leveraging the nearly Zero Energy Building (nZEB) 2020 goal because:

- hotels' guests may replicate at home the architectural solutions they experienced in the hotel;
- energy consumption in hotels is usually higher than in residential buildings, providing more opportunities for consistent energy savings;
- as the hotel sector is highly competitive, it is very likely that the advantages gained by some hotels toward the nZEB goal will push other to imitation.

1 The **Hotel Energy Solutions** is an UNWTO-initiated project in collaboration with a team of United Nations and EU leading agencies in Tourism and Energy. The project delivers information, technical support & training to help Small and Medium Enterprises (SMEs) in the tourism and accommodation sector across the EU 27 to increase their energy efficiency and renewable energy usage. http://hotelenergysolutions.net/en

2 The **RELACS (REnewabLe energy for tourist ACcomodation buildingS)** is a IEE project - launched at the end of May 2010 in Modena - involving partners from 10 countries. It aims to involve and motivate a significant number of accommodations throughout Europe (at least 60) in implementing renewable energy technologies as well as energy efficiency measures on their buildings. http://www.relacs.eu/home.php

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The neZEH project

Nearly Zero Energy Hotels (neZEH) is a 3-years long project supported by the Intelligent Energy Europe (IEE) program, started in April 2013. It involves a consortium of 7 European Countries (Croatia, France, Greece, Italy, Romania, Spain, Sweden) and 10 partners, among whom REHVA provides the technical expertise in the field of buildings energy performances.

The project aims at accelerating the refurbishment rate of existing buildings into nZEB in the hospitality sector and promoting the front runners. Particularly, neZEH focuses on the SME hotels, which represent the 90% of the European hospitality sector and are usually the most reluctant to commit to energy saving measures and to the use of renewable energies. In order to convince hotel owners to invest significantly in refitting their buildings, successful examples of existing neZEH will be showcased (**Figure 1**). The interested hoteliers will be supported in designing feasible and sustainable renovation projects: 14 pilot projects will be implemented in 7 Countries to prove the profitability of deep refurbishments achieving NZE hotels.

To achieve these goals, neZEH works within the legal framework of the nZEB implementation in each partner Country, tackling the main market barriers that prevent SME hotel owners from investing in major refurbishment projects.

Originally the project was supposed to use existing national legal requirements, but the delay in the transposition of the EU nZEB definition in most of the involved Countries, lead REHVA to face a new task: the definition of Country specific reference values using available benchmarks.

The outcomes of this preliminary study are shown in the following paragraphs.

Actual energy use of existing hotels

To understand the relevance of the energy costs on the operational costs of a tourist accommodation building at the present stage, an overview of the available data on energy use of existing hotels is provided.

BPIE data hub

After its major study *Europe's Buildings under the Microscope* (2011) [2], BPIE created a data hub for the energy performance of buildings. Refining the search for energy use of hotel buildings, relevant available data are listed for some European Member States by building age group. For this article the information extracted is per country as a maximum to minimum range of delivered energy use level set by the age groups values (**Table 1**).

Hotel Energy Solutions

The Hotel Energy Solutions (HES) project reported significant variations of energy use in facility types

Figure 1. One of neZEH project showcases: the zero energy Stadthalle Hotel in Vienna.

within the hotel sector. However, it concluded that regarding climatic conditions, overall energy use levels can be relatively constant (energy needs for cooling and heating balance out), but with significant differences in the necessary technologies to reduce energy use in different climate zones.

In addition, HES provided:

- average energy use levels according to available certification schemes for the energy performance of hotels (e.g. Accor, Nordic Swan, LowE, WWF/IBLF, Thermie) i.e.delivered energy use range **200–400 kWh/(m²·a)** with average energy use **305–330 kWh/(m²·a)**;
- definition of five energy performance ratings, shown in **Table 2**.

Comparing the values inferred from BPIE data hub and from HES, a similar range of energy use in hotels is highlighted.

ENTRANZE

To determine Country specific values, data from ENTRANZE[3] project were used. The project delivered an EU online data mapping tool including buildings' energy uses updated at 2008 (the last year with available data not affected by the economic crisis). Data about the current situation of energy use in buildings in the European Countries involved in the project were given with an energy breakdown by energy source. In the context of neZEH, data for residential buildings (**Table 3**) were used.

Consistently with the conclusions drawn by HES, which affirms that energy use levels can be relatively constant among hotels as far as energy needs for climatization are concerned, these were the functions considered to define the average energy use of hotels. These functions, here

Table 1. Max … min range of energy use for hotel buildings in some European Member States, extracted from the BPIE data hub.

N°	Country	Years	Hotels and restaurants [kWh/(m²·a)]
1	Bulgaria	1946 … 2004	350 … 217
2	Czech Republic	1900 … 2002	430 … 290
3	France	1975 … 2005	397 … 292
4	Latvia	1940 … 2010	185 … 140
5	Norway	1983 … 2011	296 … 220
6	Slovakia	1951 … 2006	545 … 190

Table 2. Hotels' energy performance rating defined in the HES project.

N°	Energy performance rating	Range [kWh/(m²·a)]
1	Excellent	< 195
2	Good	195 … 280
3	Average	280 … 355
4	Poor	355 … 450
5	Very poor	> 450

Table 3. Energy use in residential buildings with energy breakdown by energy source for the Countries involved in the ENTRANZE project.

Country	Residential Buildings Energy Consumption 2008 level	Residential Buildings Energy Breakdown by Energy Source					
		District Heating	Oil	Coal	Gas	Biomass	Electricity
	[kWh/(m²·a)]	[%]	[%]	[%]	[%]	[%]	[%]
Croatia	195	8	14	0	31	15	32
France	202	4	19	0	33	14	30
Greece	205	1	49	0	4	16	30
Italy	124	0	16	0	54	7	23
Romania	248	15	4	1	27	42	11
Spain	115	0	31	0	22	13	33
Sweden	240	33	3	0	0	14	49

3 The objective of the **ENTRANZE** project is to assist policy makers in developing integrated, effective and efficient policy packages achieving a fast and strong penetration of NZEB and RES-H/C focusing on the refurbishment of existing buildings in line with the EPBD and the RED. http://www.entranze.eu/

Articles

Table 4. Energy use in hotels with details of the increased contribution for ventilation and cooling with respect to values for residential buildings.

Country	Hotels Added Ventilation Delivered Energy [kWh/(m²·a)]	Hotels Added Cooling Delivered Energy [kWh/(m²·a)]	Hotels Added Ventilation Primary Energy [kWh/(m²·a)]	Hotels Added Cooling primary energy [kWh/(m²·a)]	Hotels Hosting Function Primary Energy 2008 level [kWh/(m²·a)]
Croatia	19,3	10,0	57,9	30,0	397,8
France	19,3	6,3	49,8	16,1	352,4
Greece	19,3	10,0	56,0	29,0	417,5
Italy	19,3	10,0	42,1	21,8	221,5
Romania	19,3	6,3	54,0	17,5	394,7
Spain	19,3	10,0	45,4	23,5	240,0
Sweden	19,3	3,8	52,1	10,1	519,8

named "hosting function", will be further specified in the paragraph *The typical energy use of a hotel.*

To use the data provided by ENTRANZE in the specific context of hotels, the energy needs for the hosting functions were considered similar to the residential buildings' ones, with an additional contribution of energy for cooling and ventilation. While the extra ventilation-related energy use was constant, the relevance of the additional cooling load depended on the climate zone. With national primary energy factors, the primary energy use of existing hotels at 2008 level was calculated, as shown in **Table 4**.

Definition of benchmarks for neZEH

One of the main expected outputs of the neZEH project is the setting up of hotels renovation projects in line with the definition of nZEB. Moreover, it is important to demonstrate to hoteliers that achieving the nZEB target is cost-effective by providing existing examples of neZEH. Both these tasks entail a practical definition of neZEH.

The typical energy use of a hotel

The first issue to be faced is how to define in a hotel the "typical use of the building", upon which the energy performance of the building is based (EPBD, Article 2) [3].

Different hotels may offer different facilities, which entails a wide gap in the energy needs even among buildings with the same general use classification. Hotels can have similar energy consumption related to the their hosting function, typically related to energy use in guestrooms, but diverse energy needs when the offered facilities are concerned.

The approach to the problem chosen by the authors was to compare the reference values for primary energy dealing only with the hotels' energy use for the hosting functions.

The selection criteria for specifying the hosting functions was suggested by the EPBD (2002) [4], affirming that the energy performance of a building derives from the climatic indoor environmental quality targets set for it. The energy performance of a building for its standard use (heating, cooling, ventilation, hot water, lighting) must refer to the standard indoor environmental conditions, which in a hotel are the comfort conditions required for guests and workers, as recommended in EN15251 [5]. With these premises, the standard zones of a hotel to be considered among the hosting functions were selected: guests' rooms; reception hall; offices; bar and restaurant; meeting rooms.

Reference values for the definition of a neZEH

The second key aspect was the definition of proper reference values for Primary Energy and integration of Renewable Energy Sources.

To define neZEH, available definitions of nZEB were grouped according to the geographical division proposed by the Ecofys report 2013 [6], in order to consider regional disparities regarding, among others, climatic and economic differences. The selected Countries representing Zones 1 (Mediterranean Europe), 2 (Eastern Central Europe), 3 (Western Central Europe) and 4 (Northern Europe) were respectively Italy, Slovakia, France and Estonia.

The final reference values are presented in **Table 5**.

Articles

It is worth noting that, at this stage, the available definitions exploited are not referred to the achievement of the cost-optimal level, despite its fundamental role for obtaining a concrete reduction on buildings' energy consumptions – especially in retrofit actions.

From primary energy values of existing hotels (**Table 4**) and neZEH values of **Table 5**, the Country specific reduction percentages were calculated. For a coherent comparison between the current and the nearly-zero energy consumption, the benchmarks set for neZEH were increased by the contribution of appliances (final values are shown in **Table 6**). The appliances impact was quantified as an extra energy use of 7 kWh/m^2 weighted by the national primary energy factors. With these adjustments, the reduction percentages, displayed in **Table 6**, ranged between 67 to 81% of the primary energy of existing hotels, with an average decrease of 74.5%, meaning that primary energy use of existing building stock need to be reduced by factor of 4 in average (varied between 3–5).

Conclusions

The first steps within the neZEH project allowed the authors to have an overview of the current situation of the European hotels' energy consumptions and of how ambitious are the targets set for reaching the nearly zero energy level.

Some available national consistent nZEB definitions allowed to determine benchmark values for nearly zero hotels in four climate zones. Comparison with existing buildings showed that the primary energy use of existing hotels is in average by factor 4 higher relative to determine neZEH benchmark values.

Table 5. Summary of the requirements for nearly zero energy hotels in Europe.

Zone	EP [$kWh/m^2 \cdot a$]	Energy uses	RES [%]
Zone 1	55	Heating, cooling, domestic hot water, HVAC aux, lighting	50
Zone 2	60		35
Zone 3	95		35
Zone 4	115		25

Being the national implementation of the nZEB definition late at the national level, the neZEH project had to face the hard task of defining its own benchmarks, by exploiting the information available so far. Therefore, despite the rigorous methodology followed to define the neZEH benchmarks, some critical considerations are needed:

- the existing definitions exploited refer to new buildings;
- the figures are now settled as fixed figures, which do not take into account the cost-optimality approach.

Considering the cost-optimal level of energy performance for refurbished buildings will necessarily lead to an increase of these benchmarks. While new buildings can nowadays be easily designed as zero energy buildings, refurbishment actions have to face many technical constraints which may not allow to reach the target. ■

References: See the complete list of references of the article in the html-version at **www.rehva.eu** -> REHVA Journal

Table 6. Reduction percentages of primary energy for existing buildings to calculate national benchmarks for hotels.

Country	Hotels hosting function Primary Energy 2008 level [$kWh/(m^2 \cdot a)$]	Hotels hosting function Primary Energy neZEH benchmark (with appliances added) [$kWh/(m^2 \cdot a)$]	Percentage reduction [%]
Croatia	398	76	81
France	352	117	67
Greece	418	76	82
Italy	222	71	68
Romania	395	79	80
Spain	240	72	70
Sweden	520	136	74

Paper V

Defining the Reference Hotel – towards nearly Zero Energy Hotels design

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Defining the Reference Hotel – toward nearly Zero Energy Hotels design

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SUMMARY

The ever mentioned "cost optimality" and "nearly Zero Energy Buildings" concepts, introduced by the EPBD recast, are still a blurry target at EU Member States' level for non-residential buildings. Among the uncertainties hampering a quantitative description of cost optimal and nearly Zero Energy (nZE) level of energy performance in these building categories, the definition of the "typical energy use of a building" [1], is a key issue. Indeed, in non-residential buildings the energy use for maintaining occupants' comfort (identified as the "typical") is complementary to the energy use for maintaining the offered services' quality. Given the general issue, the paper focuses on hotels. As an initial step toward nZE hotels, this study presents the definition of an existing Reference Hotel. First, typical and extra functions of a small-medium hotel were defined. Then, the general procedure for defining a Reference Hotel (RH) was drafted and an Italian RH was modelled: internal layout, envelope, systems features and operation profiles were identified. A dynamic energy simulation of the model was run to evaluate its energy performances. Results were then compared to benchmarks from literature. Next steps will exploit the Reference Hotel to investigate potential relations with the energy uses for extra services and to propose cost-optimal and energy efficient retrofit measures.

INTRODUCTION

In the European Commission view, Nearly Zero Energy Buildings (nZEB) and cost-optimal level of energy performance are notions that will overlap in a very near future. As widely known, both nZEB and cost-optimality were introduced in EU regulation by the recast of the Energy Performance of Building Directive [1]. nZEBs have very high energy performance and their energy need is covered to a very significant extent by energy from renewable sources. Cost-optimal level is defined the energy performance level which leads to the lowest cost during the estimated economic lifecycle. It is obtained by testing the effectiveness of several energy saving measures in improving the energy performance of buildings while taking into account their global cost. Whereas cost optimality is prescribed as the current framework regarding ambition level of typical energy performance for renovation and new buildings, nearly Zero Energy is the ambition level that Member States (MS) have to reach for all new buildings and major renovation by 1 January 2021 [2]. Because of their common nature and goal, the two energy performance levels also share the basic steps of their definition methodology, shown in Figure 1.

Figure 1. Steps of the methodology for defining cost-optimal and nZE performance levels.

In this paper the attention is focused on hotel buildings, identified as a specific building category to be considered in nZEB and cost-optimal calculations [1], but, at present, not taken into account in most of Member States. Indeed, MSs are allowed to derive all reference buildings and cost-optimal level of energy performance of the non-residential sector from basic reference buildings for offices (one RB for new buildings and minimum two RBs for existing buildings), if other specific non-residential buildings minimum requirements do not exist in their national regulations [3]. Due to the calculation efforts required, this strategy is the most widely used. Nonetheless, such an approximation may be misleading in deriving cost-optimal level of energy performance for other categories of non-residential buildings. For instance, the typical features of a hospital or a restaurant may widely differ from those of an office building. Therefore, despite not compulsory, realistic cost-optimal levels of energy performances, and consequent minimum energy performance requirements, ask for a higher number of reference buildings, when the building stock is diverse.

As a first step toward cost-optimal and nZE level of energy performance levels, the Reference Building needs to be drafted. It "represents the typical building geometry and systems, typical energy performance for both building envelope and systems, typical functionality and typical cost structure in the Member State and is representative of climatic conditions and geographic location" [3], in order to obtain representative and achievable energy performance levels as final outcomes of the methodology. Despite RBs key role, the lack of representative/reliable/detailed data about the existing building stock dampens their descriptive accuracy. Moreover, even if several past and present project collected information on the existing RBs or tried to develop national sets of RBs [4, 5, 6, 7], a procedure guiding the RBs definition is not yet clearly outlined [8].

What's "typical"?

Levels of energy performance to reach both cost-optimality and nZEB are referred to the "**typical energy use"** of a building [1], and they are based on calculation performed on Reference Buildings, which represent the **typical building-plant-operation** of the building stock [3]. However, the concept of **"typical"** is not convincingly addressed for all the building categories listed in EPBD recast [3]. EPBD [9] suggests that the energy performance of a building depends on the climatic indoor environmental quality targets set for it; therefore energy performance of a building for its standard use (heating, cooling, ventilation, hot water, lighting, possibly equipment) should refer to the standard indoor environmental conditions [10]. This approach allows considering the whole building stock as a set of "empty boxes" to which a rather uniform set of energy efficiency measures can be widely applied. In residential buildings, where maintaining the indoor environmental quality is the main goal of the systems installed, the so-defined "typical energy use" is the most suitable parameter to take into account in energy and economical evaluations. In non-residential buildings, instead, the energy use for maintaining occupants' comfort is complementary to those for maintaining the offered service's quality. Indeed, for each non-residential building use, offered services are the characterizing element and their energy consumption is very dependent on the service quality, which in turn in related to the activity's business success. In these buildings the typical energy use should be coupled with additional energy uses related to extra functions.

With these premises and with the aim to give further push to the development of non-residential (and non-office) Reference Buildings in Italy, in the following paragraphs the definition of an Italian existing Reference Hotel is outlined. Indeed, hotels exemplify the difference between typical and extra energy use of a building. Moreover, the nZEB target for hotels is object of the on-going European project "nearly Zero Energy Hotels – neZEH" [11], to which this paper may contribute. The obtained Reference Hotel is built in dynamic simulation software and evaluated in terms of typical and total energy consumption. As a final step, simulation results are compared to benchmarks value about energy use of the existing hotel building stock given by literature.

METHOD

Definition of an Italian Existing Reference Hotel

In order to define a representative Italian Reference Hotel, sub-categories of this building type were identified. Sub-categorization, despite not mandatory for MSs, is suggested by the Regulation [3] as a way to define different Reference Buildings, or the most representative one, for the main category. The different hotel typologies were defined by focusing on building parameters related to energy consumption. The selected criteria and the related classes are shown in Table 1. References and justifications for the choice and classification of each sub-category are here given:

- Climatic area; Building age. Suggested as sub-categories in [3], their division in classes, is taken from the Italian outcome of Tabula project [12]. Despite [12] only deals with residential buildings, the existing hotel stock is considered by authors very similar to the residential building stock in terms of geometry and construction typology, mirrored by each construction age.
- Hotel size. Building size is a mentioned subcategory in [3]. In the specific case of Italian hotels, size classes are provided, in terms of number of guestrooms, by Istat [13].
- Hotel category. The "stars" classification implies different minimum services to offer to guests, as required for Italy in [14], which affect the energy consumption of the building.
- Hotel opening period. This additional criteria and classification is suggested by [15], as it obviously influences the hotel plants system and energy use.

Table 1. Sub-categories and related classes for the definition a Reference Hotel.

SUB-CATEGORY	**CLASSES**							
CLIMATIC AREA	ALPINE (HDD <3000)			MIDDLE (HDD 2100-3000)			MEDITERRANEAN (HDD >2100)	
BUILDING AGE	… - 1900	1901 - 1920	1921 - 1945	1946 - 1960	1961 - 1975	1976 - 1990	1991 - 2005	2006 - …
HOTEL SIZE	SMALL (≤24 guestrooms)			MEDIUM (25-99 guestrooms)			LARGE (≥100 guestrooms)	
HOTEL CATEGORY	1*	2*	3*	4*	5*			
OPENING PERIOD	ALL YEAR			SUMMER			WINTER & SUMMER	

Further step of the existing RH developments was the identification of its detailed parameters, required to perform reliable energy calculations using a dynamic method (as suggested by [16]). The amount of information needed in this phase can be grouped in sections. Corgnati et al. [17], inspired by DOE RB models [18], defined 4 sub-sets to be detailed: form; envelope; system; operation. Brandão de Vasconcelos et al. [8] proposed to gather the detailed parameter in: configuration; constructive solutions and others. In this paper, the approach proposed by [17] was used. Irrespective of the data grouping method selected, the information can come from statistical analysis or from experts' assumptions. According to the sources available, for each sub-set of parameters different approaches may be used to create a RB, described by Tabula [12]: (1) Example Building, based on experts' assumptions and studies, when statistical data are not available; (2) Real Building, existing building with the most typical building of a certain category, based on statistical analysis, (3) Theoretical Building, virtual building with a composite of the most common features within a category of buildings.

Typical and extra energy uses of a Reference Hotel

It is worth noting that sub-categorization and statistical information for the hotel building stock only takes into account features related to hosting functions, such as guestrooms number and equipment or reception and common areas services and opening times [13, 14]. Neither minimum requirements nor statistical data are given for extra services offered in hotels, e.g. fitness area, laundry or kitchen. Indeed different hotels offer a wide range of facilities, which entails a significant gap in total energy needs among buildings with the same general use classification, showing, in turn, similar energy consumption related to the their hosting function [10]. It may be derived that the "typical energy use" in hotels refers to the energy used to maintain indoor environmental comfort conditions related to hosting functions, that can be identified in guestrooms, reception hall, offices, bar and restaurant, meeting rooms. Following EU dispositions, these functions will be accounted for the definition of the Reference Hotel energy use. However, extra functions have complementary energy uses that cannot be disregarded, since their presence influences both the whole building energy performance and the hotel business success. Their relevance in the hotel energy balance is analyzed in this paper by applying the basic principle of the superposition of effects. Kitchen and fitness area, most common extra functions in the Italian hotel stock, are implemented as "additional entities" to the Reference Hotel hosting functions, in order to point out their role on the hotel total energy use.

Reference Hotel dynamic energy simulation and benchmarking

The defined Reference Hotel model was built in Energy Plus by implementing the detailed information previously gathered about form, envelope, system and operation. Once the building location was selected, an annual simulation was run. Outcomes were reported for typical (hosting functions) and extra energy uses (kitchen and fitness area) of the building. Results were expressed both in terms of delivered and of primary energy, for which Italian Primary energy conversion factors, given in [19], were applied (1,05 for Natural Gas, 1,95 for Grid Electricity).

As a final step, results were related to existing figures in literature. The RH simulated delivered energy was compared to 2 different energy efficiency ratings for existing hotels, reported in Table 2. The RH Primary Energy was compared to the preliminary assumption of neZEH project about primary energy use for hosting functions in Italian hotels, 222 kWh/m^{2}y [10].

Table 2. Energy efficiency rating for existing hotel (delivered energy) proposed by [20] and [21]

Energy performance rating	Rating [20]	Rating [21]
	Small hotels (4-50 rooms) without laundry, with heating and air conditioning in some areas	all hotel types
	Range [kWh/m^{2}y]	Range [kWh/m^{2}y]
Excellent	-	<195
Good	<240	195 – 280
Average	240-290	280 – 355
Poor	290-340	355 - 450
Very poor	>340	>450

RESULTS

An Italian Reference Hotel

Following Tabula procedure [12], the study focused on the **Italian Middle climatic zone**, where a **medium size**, **3 stars** hotel, **open all year** and built between **1921-1945** was selected as the subcategory of Reference Hotel to be developed, because:

- in the Italian middle climatic zone (e.g. Turin, Milan), urban hotels devoted to business and cultural tourism - therefore open all year - are representative of an important share of the accommodation market [15];
- 3 stars hotels represent the highest share of businesses (45%) and beds (43%) of the Italian stock [13, 22];
- medium size hotels, more common in the urban contexts, are the 42% of businesses and 56% of guests' beds of the Italian hotel offer [13, 22];
- hotel businesses increased constantly from 1930 onwards [22]. Hotels built between 1921 and1945 are taken as example of early stage buildings asking for deep retrofit actions.

The identified Reference Hotel sub-category was then developed in terms of detailed parameters, collected in 4 sections [17] and applying the approaches suggested by Tabula project [12]. The approaches implemented in the present study are presented in Figure 2 and references for each section are here detailed:

- "**Form**". Statistical information about the hotel building stock in terms of size, accommodation capacity, category and location were taken from the Italian statistic institute [13]. Based on these data, a real building representing the average stock for the chosen hotel subcategory was selected. Due to a lack of information about other dimensional/geometrical features of the hotel stock, the choice of a real hotel building, elected by statistics as representative of a specific category, was the only possibility to have enough detailed data to build a simulation model.
- "**Envelope**". Information were derived from the Italian Building Typology brochure [12], outcome of Tabula project, based on the review of the real building envelope features. Construction techniques adopted for hotel buildings were assumed by authors to be very similar to those for residential buildings, specific object of [12]. Indeed the selected real building envelope characteristics (not detailed enough to be used) are very similar to the features proposed by [12].
- "**System**". Specific information were derived from experts assumptions used in Tabula project [12] for heating and from field research findings presented in [15] for cooling.
- "**Operation**". Data were generally derived from DOE "Small Hotel" Reference Building [7], based on US typical operation schedules derived from methodologies (2) and (3). Set-points were derived from EN15251 [23], in order to comply with European requirements.

The same procedure was applied to describe the features of kitchen and fitness area, for which specific schedules related to extra services of the hotel were adapted to the Italian hotel context.

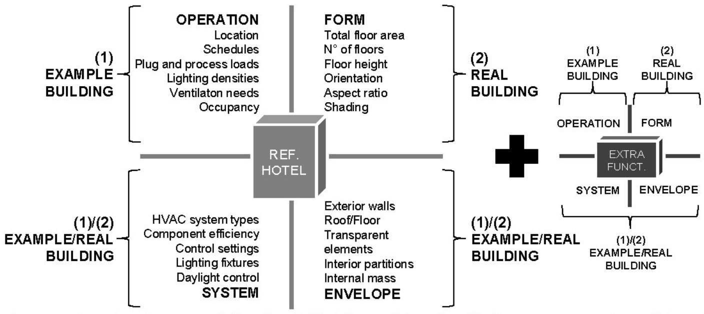

Figure 2. Approaches implemented for the definition of the detailed parameters describing the RH.

Table 3 summarizes the obtained RH main features and Figure 3 displays its internal layout.

Table 3. Italian existing RH main characteristics regarding form, envelope and system.

	BUILDING CHARACTERISTICS	UNIT	DATA	DATA SOURCE
FORM	Gross area	m^2	2117	real building
	Gross conditioned area	m^2	1700	real building
	Average gross area/floor	m^2	423	real building
	Number of floors	-	5 (4 + basement)	real building
	Orientation	-	S-N	real building
	Aspect ratio (S/V)	-	0.28	real building
	Floor height (clear height + ceiling)	m	3.5	real building
	Number of façades	-	3	real building
	Façades total area	m^2	1275	real building
	Opaque façades area	m^2	1059	real building
	Window/Wall ratio	-	0.17	real building
	Number of guestrooms	-	49	real building
	Average guestrooms area	m^2	21	real building
	Number of beds	-	95	real building
ENVELOPE	External walls construction	-	Hollow wall brick masonry (U=1.1 W/m²K)	[12], selection based on real building site visit
		-	Hollow brick masonry, low insulation (U=0.8 W/m²K)	[12], selection based on real building site visit
	Internal walls construction	-	Hollow brick wall (U=2.3 W/m²K)	real building
	Ground floor construction	-	Concrete floor on soil (U=2.0 W/m²K)	[12], selection based on real building site visit
	Floors construction	-	Floor with reinforced brick-concrete slab (U=1.65 W/m²K)	[12], selection based on real building site visit
	Roof construction	-	Floor with reinforced brick-concrete slab, medium insulation (U=0.7 W/m²K)	[12], selection based on real building site visit
	Windows	-	Single glass wood frame (U_w=4.9 W/m²K, g=0.85)	[12], selection based on real building site visit
		-	Single glass, metal frame without thermal break (U_w=5.7 W/m²K, g=0.85)	[12], selection based on real building site visit
	Doors	-	Glass and metal doors thermally improved (U_w=3.8 W/m²K, g=0.75)	[12], selection based on real building site visit
SYSTEM	Ventilation	-	Natural	[12], selection based on real building site visit
	Heating system	-	Centralized, with radiators	[12], selection based on real building site visit
	Heating energy source	-	Natural gas	[15], confirmed by the real building site visit
	Cooling system	-	Centralized, with split	[15], confirmed by the real building site visit

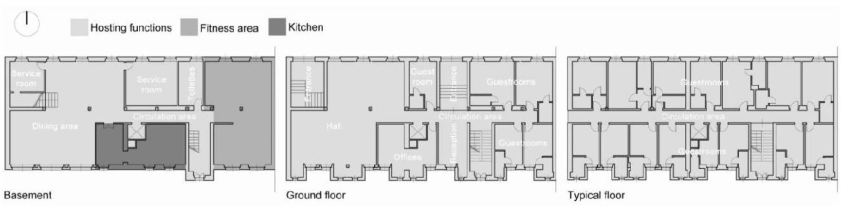

Figure 3. Italian existing RH internal layout for basement, ground floor and typical floor.

RH simulation results

For the purpose of the simulation, the RH was located in Turin (HDD=2617), representative of the Italian Middle Climatic Zone. Its annual delivered and primary energy use are reported in Table 4 with regard to its end-uses and in Table 5 with regard to the relevance of its hosting and extra-functions.

Table 4. Delivered and primary energy use of the Italian existing RH for its end uses.

End use	**Electricity**	**Natural Gas**	**Primary Energy (PE)**	**Share of PE for end-use**
	kWh/m^2y	kWh/m^2y	kWh/m^2y	-
Lighting	54.36	-	106.00	27.1%
Equipment	64.48	2.19	128.03	32.7%
Fans & Pumps	4.69	-	9.14	2.3%
Cooling	48.60	-	94.77	24.2%
Heating and DHW	0.03	50.98	53.58	13.7%
TOTAL	172.16	53.17	391.53	100%

Table 5. Primary energy use of the Italian existing RH for its functions.

Function		**Hosting functions**	**Fitness area**	**Kitchen**
Share of the whole Primary Energy use		90.56%	6.26%	3.18%
Specific primary Energy use [kWh/m^2y]	Lighting	104.62	167.87	53.65
	Equipment	127.96	85.95	211.63
	Fans & Pumps	9.14	9.14	9.14
	Cooling	98.23	46.83	22.99
	Heating and DHW	36.44	335.16	326.31
	TOTAL	376.39	644.94	623.72

DISCUSSION

Built on the EPBD recast dispositions, the paper aimed at drafting an Italian existing Reference Hotel, and, from a wider standpoint, to point out the need for a wider range of RBs, in order to achieve realistic cost-optimal minimum energy requirements. The RH, modeled following procedures suggested by literature and based both on literature and observed data, was simulated in Energy Plus. Simulation results are intended to show the energy performance level of a hotel building, in relation to the existing benchmarks for hotel energy efficiency.

In terms of delivered energy of the whole building, according to the proposed classifications [20, 21] the defined RH is ranking “good” (225.33 kWh/m^2y). However, these rankings may be too generic since they do not consider distinction among the services offered by hotels (except from specification about laundry). Dealing with Primary Energy, remarks are two-sided:

- on the one hand, the hosting functions’ primary energy use (376.39 kWh/m^2y) is 76% higher than the average value for the Italian hotel stock identified by neZEH project (222 kWh/m^2y) [10]. However, the neZEH benchmark is based on analysis of the residential building stock, to which standard extra energy uses for cooling and ventilation were added. The primary energy results here presented may lead to the conclusion that in Italy hotels energy use for hosting functions is not comparable with residential ones.
- on the other hand, the extra functions simulated for the RH, despite their small relevance in terms of floor area (6%) and the low profile offered services (fitness area with gym equipment and kitchen serving breakfast only), accounts for approximately 10% of the whole building primary energy use, with specific primary energy consumption 66%

(kitchen) and 71% (fitness area) higher than the one for hosting functions. These results suggest that, when dealing with retrofit measures options for hotels, extra services need to be accounted.

Taking advantage of these findings and considerations, next steps of the research will take the presented RH as the baseline model to apply retrofit measures in view to achieve the cost-optimal and the nZE level of energy performance.

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Paper VI

NZEB, cost- and comfort-optimal retrofit solutions for an Italian Reference Hotel

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NZEB, cost- and comfort-optimal retrofit solutions for an Italian Reference Hotel

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SUMMARY.

With Nearly Zero Energy Building (NZEB) performance levels finally defined in most of EU countries, nowadays is it possible to quantify the financial and energy performance gaps between cost-optimal, mandatory by law and NZEB design solutions, addressing the deployment of energy efficiency plans. In this framework, this paper studies how far cost-optimality is from the NZEB level for an Italian Reference Hotel (RH) undergoing major renovations.

The RH was the starting point for testing various retrofit options via dynamic energy simulations. Performances of each retrofit option were compared with the Italian NZEB requirements, in turn obtained through the calculation of the energy performance of a fictional *baseline building*. The comparative energy analysis confirmed that, with a proper combination of measures implementing standard technologies, the Italian NZEB target could be met. Following the cost-optimal analysis precepts, the obtained results were set against the financial convenience of the simulated design options. These outcomes quantified the worrying existing gap between financially interesting retrofit solutions and the NZEB ones.

In its final section, the paper investigates the comfort-related consequences of the proposed retrofit options, suggesting comfort as an additional variable to be considered during the investment decisional phase. The energy performance indicators were plotted versus thermal comfort ones so that a novel comfort-optimal graph was obtained.

Key words: NZEB, Hotel, Cost-optimal, Thermal Comfort.

1. INTRODUCTION

In 2010, the EPBD recast (European Commission, 2010) introduced the NZEB concept and by January 2021 all over Europe new private buildings will have to comply with nationally defined NZEB standards. Accordingly, most of MSs have now endorsed EU requirements in their regulations and set numerical indicators for new and existing buildings aiming to reach the NZEB level (BPIE, 2015). In the EU view, these national figures should also represent the cost-optimal level of energy performance from 2021 on, meaning that NZEB design options should be those leading to the lowest global cost during the estimated lifecycle of buildings. Indeed, EPBD recast also introduced cost-optimal methodology as the guiding principles for setting building energy requirements.

However, the envisaged full match between cost-optimal and NZEB energy performance level remains an open issue. Studies investigating the possible energy/financial performance gaps between the two levels can inform policy-makers about how demanding the forthcoming market transition towards an energy efficient building stock will be. To serve the cause, in the present paper the matter was investigated for the proposal of retrofit solutions for a Reference Hotel located in Italy, where NZEB minimum requirements are available since June 2015.

Several reasons led the authors to deal with hotel buildings. Primarily, hotels well represent a wide spectrum of non-residential buildings where multiple functions are in place. While cost-optimal and NZEB studies have flourished in recent years for residential (e.g. Becchio et al., 2015) and office buildings (e.g. Congedo et al., 2015), other non-residential categories have been rarely investigated. Nonetheless, the mixed energy uses of multi-functional non-residential buildings represents an interesting challenge for the simultaneous achievement of cost-optimal and NZEB performances. Additionally, hotels are highly regarded by the international community for their role in the transition towards a low-carbon society. This building category ranks third for specific energy uses of the non-residential EU stock (BPIE, 2011); given the drastic reduction in CO_2 emissions that is expected for the building sector by 2050 in Europe (European Commission, 2011), high performing design solutions for hotel buildings have been strongly promoted by the European Commission in the last years, for instance through the neZEH project (Tournaki et al., 2014). The role of tourism accommodations in sustainable development gained further attention in 2017, which was nominated "International Year of Sustainable Tourism for Development" by the United Nations General Assembly. Accommodation structures are accounted to be responsible for more than 20% of the total tourism-related emissions (UNWTO et al., 2008) and a drastic shift in the management of these businesses could significantly contribute the economic, social and environmental dimensions of sustainable development (UN, 2015). In this framework, the focus of the paper on the retrofit of an Italian Reference Hotel can represent an interesting case study at a broad scale, as Italian hotels represent 18% of the EU hotel stock (BPIE, 2011).

Finally, the specific nature of hotels, buildings and businesses at once, gives the chance of coupling cost-optimal analysis with investigations on comfort conditions. Indeed, in order to run a successful accommodation business, reduced operational costs (e.g. energy costs) must be coupled with guests' satisfaction, which chiefly requires comfortable indoor conditions (Gao and Mattila, 2014). Moreover, indoor comfort is widely recognized as an important co-benefit of energy efficient buildings from the macro-economic perspective as well (IEA, 2014).

Building upon these premises, in the followings of the paper the Reference Hotel is introduced and investigation methods and results are presented for the performed energy, financial and comfort analyses.

2. CASE STUDY

Cost-optimal and comfort analyses were carried out for a fictional Reference Hotel, modelled following the EPBD recast's precepts. In the European Commission's view, Reference Buildings (RBs) are models based on a solid understanding of the building stock and representative of the typical and average building typologies across Europe (European Commission, 2012). Developing energy and economic analysis for these models allow the results to be relevant for a wide pool of buildings.

The RH portrays an Italian a 3-star, medium-size, urban hotel, open all year, built between 1921 and 1945 and located on the Italian Middle Climatic zone (Heating Degree Days (HDD) = 2100-3000). This building sub-category was selected because of its statistical relevance in the Italian hotel stock; its representative building was modeled based on statistical data and experts' assumptions, in accordance with Corgnati et al.'s RB modeling approach (Corgnati et al., 2013). The main features of the obtained Italian RH, extensively described by Buso et al. (2015) are recalled in Table I. The RH energy performances were simulated in Energy Plus 8.3, selecting Turin (HDD = 2842, Cooling Degree Days = 287) as representative location.

Table I – RH main features for form, envelope, system and operation.

Class of parameters	Parameter	Unit	Value
Form	Gross conditioned area	m^2	1700
	Number of floors	ND	5 (4 + basement)
	Orientation	ND	S-N
	Aspect ratio (S/V)	ND	0,28
	Window/Wall ratio	ND	0,17
	Number of guestrooms	ND	49
	Number of beds	ND	95
Envelope	Average opaque envelope U	$W/(m^2K)$	1,17
	Average glazed envelope U	$W/(m^2K)$	5,46
System	Ventilation	ND	Natural
	Heating system	ND	Centralized, with radiators
	Heating energy source	ND	Natural gas
	Cooling system	ND	Centralized, with split
Operation	Schedules	ND	UNI 10339:2009, EN15251

3. METHOD

The research was developed through the following steps:

i. Definition of the minimum and NZEB level of energy performance requirements for the RH, according to the Italian regulation.
ii. Cost-optimal analysis oriented to meet the NZEB target for the retrofitted RH.
iii. Thermal comfort analysis assessing the effects of retrofit solutions on the comfort level in guestrooms, in view of developing a comfort-optimal graph.

3.1 (i) Definition of minimum and NZEB energy performance requirements

The inter-ministerial decree (d.i.) "Requisiti Minimi" (Ministero dello Sviluppo Economico, 2015) came into force in October 2015 as the regulatory tool announced in Law 90/2013 (Presidente della Repubblica, 2013), which, in turn, transposed the EPDB recast to the Italian context. The decree defines the requirements for NZEBs and sets updated minimum energy standards, differentiated for new buildings, degree of renovation and for target year. The main characterizing feature of the d.i. is the performance-based approach proposed to verify the compliance with energy requirements for new buildings and major renovations. Indeed, they are based on the concept of *baseline building*. The *baseline building* is as a fictional building having the same geometry, orientation, geographic location, purpose of use and type of systems than the building object of the evaluation, but implementing pre-defined thermal and energy features (e.g. envelope U-values and plants efficiency). The limit values for the building under evaluation refer to envelope thermal properties ($H'_{T,}$, $A_{sol,est}/A_{sup\ utile}$), heating and cooling energy needs ($EP_{H,nd}$ and $EP_{C,nd}$) and total primary energy use ($EP_{gl,tot}$), that in non-residential buildings includes energy uses for heating, cooling, domestic hot water, ventilation, artificial lighting and lift systems. Coming to the minimum share of Renewable Energy Sources (RES) to be exploited on-site, the d.i. refer to D.lgs.28/2011 (Presidente della Repubblica, 2011). While envelope-related and RES requirements are established with a traditional prescriptive approach, the energy-related ones are obtained through the calculation of the energy performance of the *baseline building*. Based on the decree's dispositions, it is possible to derive 2 levels of minimum energy requirements, mandatory for private buildings from 2015 and from 2021, and the NZEB requirements. The building under evaluation can meet these requirements through any suitable combination of Energy Efficiency Measures.

In this paper, *baseline* models of the RH were built in Energy Plus, in order to easily spot the performance gap between the RH in its original configuration and the *baseline* RHs.

3.2 (ii) Cost-optimal analysis towards the NZEB target

The well-established steps of cost-optimal analysis foresee (a) the definition of several Energy Efficiency Measures (EEMs) to be combined and hypothetically implemented in the building object of investigation and the (b) energy and (c) economic analysis of the so-obtained models. In particular, for these retrofit options primary energy and global cost have to be calculated for the creation of the cost-optimal graph (d). Results highlight retrofit options whose primary energy uses lead to the minimum life cycle cost, i.e. the cost-optimal retrofit options.

a. EEMs. In the present paper, EEMs were implemented in the RH model with the aim of reaching the NZEB level. To this purpose, packages of EEMs were assembled in order to verify by subsequent steps the NZEB requirements. First, envelope-related EEMs and packages (PE) were created to verify compliance with envelope-related NZEB requirements. PEs meeting these requirements were the basis for the implementation of artificial lighting measures (PEL). PE and PEL were analyzed in terms of heating and cooling energy needs and the packages satisfying the related requirements were the baseline models for the implementation of systems, plants and renewable energy measures. Table II summarizes and describes the selected EEMs and Table III reports the created packages of envelope EEMs (PE). Other packages of EEMs were created by adding lights, system, plants and RES measures to the PEs in line with NZEB requirements. In the followings of the paper, these packages will be named according to the features they implement: e.g. in package PE10L1.2S1.1S4.2R1.1R2.2, envelope is upgraded as foreseen by PE10, lights are substituted according to L1.2, system and plants are replaced as described by S1.1 and S4.2 respectively and renewables are installed according to R1.1 and R2.2.

Table II – Energy Efficiency Measures (EEMs) applied to the RH.

EEM type	EEM code	Description	
Envelope	E1.1	External walls insulation level 1	U < 0,30 W/(m^{2}K)
	E1.2	External walls insulation level 2	U < 0,26 W/(m^{2}K)
	E2.1	Groundfloor insulation level 1	U < 0,30 W/(m^{2}K)
	E2.2	Groundfloor insulation level 2	U < 0,26 W/(m^{2}K)
	E3.1	Semi-exposed ceiling insulation level 1	U < 0,25 W/(m^{2}K)
	E3.2	Semi-exposed ceiling insulation level 2	U < 0,22 W/(m^{2}K)
	E4.1	Windows substitution level 1	U < 1,80 W/(m^{2}K)
	E4.2	Windows substitution level 2	U < 1,40 W/(m^{2}K)
	E5.1	Fixed shading	
	E5.2	Automated shadings	
Lights	L1.1	Substitution of all CFLs with LED lights	
	L1.2	Substitution of CFLs with LED lights in common and working areas	
System	S1.1	Substitution of heating and cooling terminals with four-pipes fancoils	
	S1.2	Substitution of heating and cooling terminals with radiant floor	
	S1.3	Substitution of heating and cooling terminals with radiant ceiling	
Plant	S4.1	Substitution of condensing boilers with an air-to-water heat-pump	
	S4.2	Substitution of condensing boilers with District Heating	
RES	R1.1	Installation of 22 Solar Thermal (ST) Panels	
	R1.2	Installation of 11 Solar Thermal (ST) Panels	
	R2.1	Installation of 84 Solar Photovoltaic (PV) Panels	
	R2.2	Installation of 56 Solar Photovoltaic (PV) Panels	

Table III – Packages of envelope-related EEMs.

Code	Description	Code	Description
PE1	E1.1+E2.1+E3.1	PE10	E1.2+E2.2+E3.2+E4.2+E5.1
PE2	E1.2+E2.2+E3.2	PE11	E1.1+E2.1+E3.1+E4.2
PE3	E4.1+E5.1	PE12	E1.2+E2.2+E3.2+E4.1
PE4	E4.2+E5.1	PE13	E1.1+E2.1+E3.1+E4.2+E5.1
PE5	E1.1+E2.1+E3.1+E4.1	PE14	E1.2+E2.2+E3.2+E4.1+E5.1
PE6	E1.2+E2.2+E3.2+E4.2	PE15	E1.2+E2.2+E3.2+E4.1+E5.2
PE7	E1.1+E2.1+E3.1+E5.1	PE16	E1.2+E2.2+E3.2+E4.2+E5.2
PE8	E1.2+E2.2+E3.2+E5.1	PE17	E1.1+E2.1+E3.1+E4.2+E5.2
PE9	E1.1+E2.1+E3.1+E4.1+E5.1	PE18	E1.2+E2.2+E3.2+E4.1+E5.2

b. Energy analysis. The energy analysis was performed with the two-folded aim of satisfying the minimum and NZEB requirements and of finding the cost-optimal level of energy performance for the RH. In view of scoring the first goal, envelope thermal properties, heating and cooling energy needs, energy produced from RES and delivered energy were obtained through Energy Plus simulations. Then, the share of renewables was calculated according to the Italian standards UNI-TS 11300-4 (UNI, 2016) recommendations and the delivered energy data were converted into primary energy by applying the Italian conversion factors given in the d.i.. The obtained total global primary energy index ($EP_{gl,tot}$) was used to score the second goal of the energy analysis, i.e. as the primary energy indicator in the cost-optimal graph.

c. Financial analysis. Global cost was calculated as shown in Formula 1:

$$C_G(\tau) = C_I + \sum_j \cdot [\sum_{i=1} (C_{a,i}(j) \cdot R_d(i)) - V_{f,\tau}(j)] \qquad (1)$$

where $C_G(\tau)$ represents the global cost referred to starting year τ_0, C_I is the initial investment cost, $C_{a,i}(j)$ is the annual cost for component j at the year i (including running costs and periodic or replacement costs), $R_d(i)$ is the discount rate for year i, $V_{f,\tau}(j)$ is the final value of component j at the end of the calculation period (referred to year τ_0). The discount rate R_d is used to refer the costs to the starting year τ_0; it is expressed in real terms, hence excluding inflation.

For the RH and for each model implementing EEMs all the data were defined and the global cost was calculated adopting a microeconomic (i.e. investors') perspective. The calculation period τ was set as 20 years; 4% discount rate was used (European Commission 2012); investment costs were taken from Piedmont Price List 2015 (Regione Piemonte, 2014) and they were increased by the Italian VAT (22%) and professional fees, while possible subsidies were excluded from the calculations; replacement and maintenance costs were derived from EN 15459:2007 Appendix A (CEN, 2007a); energy costs were calculated by applying to Energy Plus simulation results the following energy tariffs (including taxes), derived from real hotels bills: natural gas = 0,077 €/kWh; electricity = 0,231 €/kWh; district heating = 0,092 €/kWh (space heating), 1679 € + 0,071 €/kWh (domestic hot water).

d. Cost-optimal graph. Final outcome of the cost-optimal analysis was a scattered dots graph, were global costs were plotted versus the corresponding primary energy indexes, in order identify the cost-optimal retrofit solutions and to spot the existing energy and economic gap between these solutions and the ones meeting the NZEB target.

3.3 (iii) Thermal comfort analysis

The Reference Hotel is a mechanically heated and cooled building whose main users, guests, have high level of expectations in terms of comfort. Here-hence, the RH thermal environment operative conditions were set according to EN15251 I Comfort Category (CC) (CEN, 2007b); thus, operative temperature set-points for heating and cooling were respectively 21°C during occupied hours from October 15th to April 15th, and 25,5°C during occupied hours from April 15th to October 15th. Aim of this section of the study was to verify if the envisaged building/system retrofit configurations were able to guarantee the RH design thermal comfort conditions (I CC) to guests.

EN15251 Standard (CEN, 2007b) recommends PMV-PPD indexes (Fanger, 1970) as the most suitable indicators of the thermal comfort level of a mechanically conditioned building. It also suggests that thermal performances can be evaluated by calculating the number of occupied hours (those during which the building is occupied) when the comfort criteria are met. Comfort criteria (i.e. Comfort Categories) expressed as a function of PMV are reported in Table IV.

Based on these recommendations, the hourly PMV values for a standard guestroom were retrieved from the dynamic simulations outputs and compared with the PMV comfort category limits. Additionally, these thermal comfort performance indicators were plotted versus the primary energy indexes in order to put in relation comfort and energy performances of the investigated retrofit options and to spot comfort-optimal solutions.

Table IV – EN15251 (CEN, 2007b) Indoor Environmental Quality categories for thermal comfort requirements for spaces with sedentary activities.

Category	Applicability	PMV limit values
I	High level of expectation	-0.2 < PMV < + 0.2
II	Normal level of expectation	-0.5 < PMV < + 0.5
III	Moderate level of expectation	-0.7 < PMV < + 0.7
IV	Values outside the above categories	PMV < -0.7 or PMV > + 0.7

4. RESULTS AND DISCUSSION

Results are presented separately for each of the research steps listed in Section 3.

4.1 (i) Definition of minimum and NZEB energy performance requirements

In accordance with the d.i. "Requisiti Minimi", Table V summarizes the minimum requirements for 2015, 2021 and NZEBs, as well as the RH original performances.

Table V – minimum and NZEB requirements for the RH vs. RH performances.

Requirement	Limit values			RH
	2015	2021	NZEB	
H'_T	≤0,75			2,22
$A_{sol,est}/A_{sup\ utile}$	≤0,04			0,03
$EP_{H,nd}$	27,6	24,1		69,3
$EP_{C,nd}$	25.72	27,5		20,9
$EP_{gl,tot}$	182,9	180,2		265,3
$\eta_{H,}$	0,81 (U), 0,95 (G)			0,84 (U), 0,97 (G)
η_W	0,70 (U), 0,85 (G)			0,70 (U), 0,97 (G)
η_C	0,81 (U), 2,50 (G)			0,70 (U), 2,61 (G)
RES_{DHW}	50%			0%
$RES_{DHW,H,C}$	50% *			0%

Notes: * from January 2017, 50% is the minimum $RES_{DHW,H,C}$ for all new buildings and major renovations; (u) = Use efficiency; (g) = Generation efficiency

Starting from January 2017 the 2021 and NZEB requirements fully overlap. This is in line with EPBD recast dispositions', which envisage all new buildings to be NZEB from 2021. Moreover, it can be noticed how 2015 mandatory requirements just slightly differ from the NZEB ones. In view of these facts, only NZEB requirements were selected for comparison with the energy performances of the proposed retrofit options.

EEMs are required to fill the gap between the Reference Hotel original performances and its NZEB *baseline* counterpart. In particular, the transmission heat transfer coefficient H'_T must be lowered by almost 2 times, a 32% reduction is required for the primary energy index $EP_{gl,tot}$ and a 65% reduction is necessary to meet the heating energy need requirements $EP_{H,nd}$. Conversely, cooling energy need limit slightly increased due to the better thermal envelope properties of the *baseline* RH.

4.2 (ii) Cost-optimal analysis towards the NZEB target

EEMs and Energy analysis. The creation process of packages of EEMs went along with the energy analysis towards the fulfilment of the NZEB level. Only packages meeting the envelope and energy needs performance requirements were further investigated in terms of primary energy performance and share of renewable energy. Figure 1, 2 and 3 display this combined energy analysis and packages selection procedure: in each figure the horizontal dotted line highlights the NZEB limit for the analyzed requirement and the yellow rectangles identify the retrofit solutions complying with it.

Figure 1 reports H'_T values of models implementing envelope related EEMs and shows that only packages envisaging an overall envelope upgrade (opaque + glazed surfaces) can satisfy minimum/NZEB requirements.

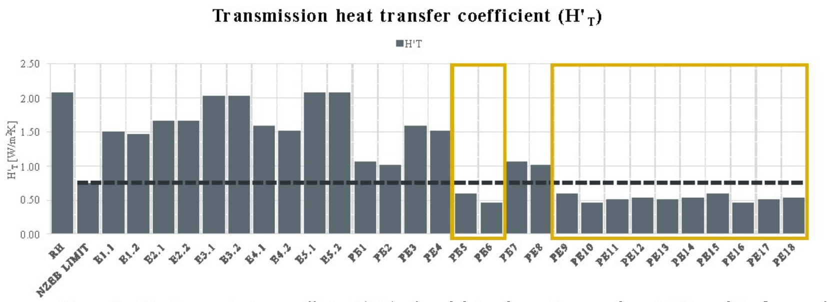

Figure 1 – Heat transmission coefficient (H'_T) of models implementing envelope EEMs and Packages of envelope EEM, in comparison with the NZEB limit value (dotted horizontal line).

Figure 2 reveals that only PE10L1.2, in which the combination of high level of insulation, fixed shadings and partial lights substitution was tested, was able to simultaneously meet the $EP_{H,nd}$ and $EP_{C,nd}$ requirements. In Figure 3, $EP_{gl,tot}$ and RES share of packages of EEMs including systems and plants measures are shown. It can be noticed that none of the retrofit options complies with both Primary Energy and Renewables limit values. Even if 10 packages are able to outperform the $EP_{gl,tot}$ and RES_{DHW} requirements, $RES_{DHW+H+W}$ is always below the mandatory minimum share.

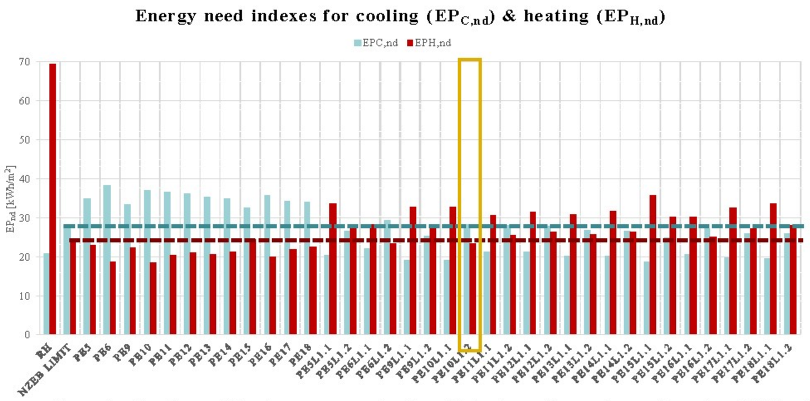

Figure 2 – Cooling and Heating energy needs of models implementing packages of envelope EEM and packages of envelope&lights EEMs, in comparison with the NZEB limit value (dotted horizontal line).

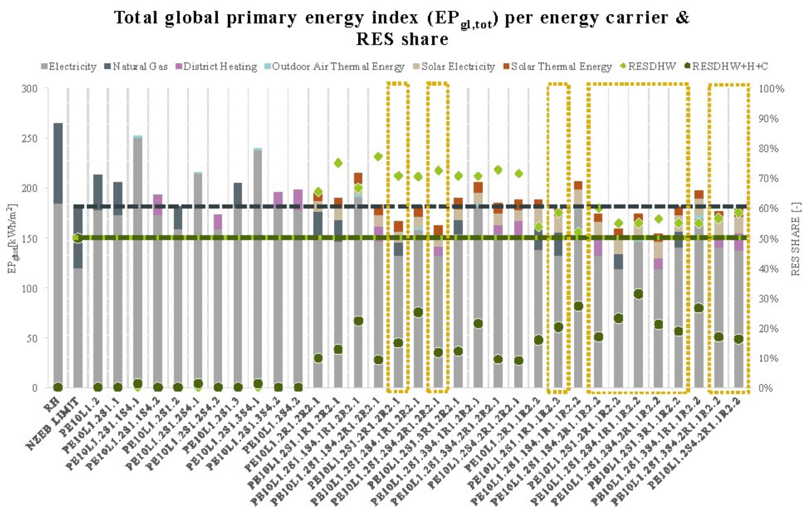

Figure 3 – Total global primary energy index ($EP_{gl,tot}$) per energy carrier (on the left y-axis) and RES share (on the right y-axis) of models implementing packages of envelope, lights, systems, plants and RES EEMs, in comparison with the NZEB limit values (dotted horizontal lines).

Reasons for the disappointing share of renewable energy sources may be found in the high electricity energy use for climatization purposes (fans and pumps, cooling and heating in case of heat-pump installation), that Photovoltaic (PV) panels on roof south slope cannot compensate. Additionally, the air-to-water heat-pump, when present, was not able to exploit the outdoor air thermal energy to produce heat. Despite the considered retrofit options were not able to formally reach the NZEB level, simulations results provide encouraging perspectives for the retrofit of existing hotels. The object of analysis is an energy-intensive building located in a densely built context. These factors prevented the effective exploitation of RES. Nonetheless, the implementation of standard retrofit options allowed it to comply with NZEB primary energy requirements.

Financial analysis and cost-optimal graph. In Figure 4 the primary energy and global cost data for all the simulated packages of EEMs are summarized in a scattered plot, from which the cost-optimal curve (red dotted line in the graph) is derived.

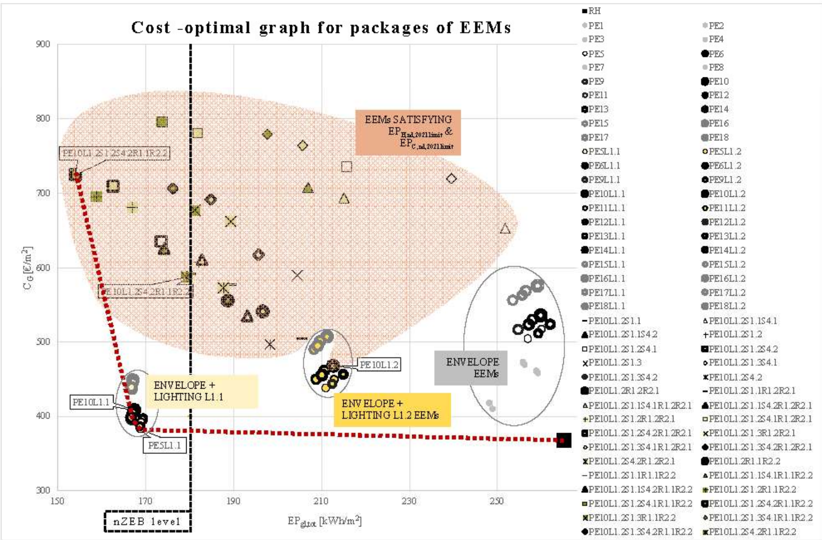

Figure 4 – Cost-optimal graph, in comparison with NZEB primary energy requirements.

Results deceptively show that the cost-optimal option is represented by the RH without retrofit, as it has the lowest global cost. In general, the missing balance between investment costs and energy costs reduction is the reason for the recorded disappointing financial performances. However, undertaking an overall envelope and artificial lighting upgrade can significantly decrease the primary energy use of the hotel with an irrelevant increase in global cost. In particular, package PE5L1.1 showed the best combination of energy and financial performance. It entailed a 4% increase in C_G and a significant -36% in the $EP_{gl,tot}$ with respect to the RH. Unfortunately, the promising primary energy performances of PE5L1.1 and similar packages do not allow to define them as NZEB retrofit options. Indeed, packages envisaging the overall substitution of artificial lights had too high heating energy needs, when compared to the NZEB limit (see Figure 2). Conversely, the top point of the cost-optimal curve – PE10L1.2S1.2S4.2R1.1R2.2 - met the NZEB energy performance requirements (climatization needs and primary energy), with a 42% $EP_{gl,tot}$ reduction. Unfortunately, its C_G almost doubled (+97%) the RH's C_G. Other retrofits option met both the energy needs and the primary energy requirements, presenting slightly higher $EP_{gl,tot}$ and lower C_G. Among them, PE10L1.1S4.2R1.1R2.2 showed the lowest global cost.

Based on Figure 4, it is possible to quantify the energy and financial performance gap between cost-optimal and NZEB retrofit options. The cost-optimal level of energy performance can be identified in the $EP_{gl,tot}$ of PE5L1.1 (169 kWh/m^2), while the NZEB EP_{gl} is fixed at 180 kWh/m^2. Therefore, in terms of Primary Energy, cost-optimal and NZEB level do overlap. However, the energy needs of the cost-optimal package of EEMs does not comply with the NZEB requirements. To evaluate the financial gap, the C_G of the cost-optimal package PE5L1.1 (382 €/m^2) was compared with the C_G of package satisfying the EP NZEB requirements with the lowest C_G (587 €/m^2), PE10L1.2S4.2R1.1R2. The important cost difference – 205 €/m^2 – stresses the existence of market barriers toward the market up-take of NZEB renovations. Additionally, it must be noted that package PE10L1.2S4.2R1.1R2.2, here identified as representative of an NZEB renovation, in fact cannot be considered a NZEB renovation, as it is not able to cover the minimum $RES_{DHW+H+W}$ (see Figure 3). To satisfy this requirement, additional PV or ST panels may be installed, entailing on the one hand decreased energy costs, on the other hand an increase in the initial investment costs. It is licit to infer that, in order to fully satisfy NZEB requirements, the financial gap will further widen.

4.3 (iii) Thermal comfort analysis

The analysis aimed at investigating the thermal comfort conditions of a typical south-oriented guestroom during its occupied hours for all the analysed simulation models. The imposed operative conditions were based on the I Comfort Category, therefore the study focused on verifying the frequency of occupied hours during which the PMV values lied in the (-0,2)/(+0.2) range (i.e. the I CC limits) during the annual simulations.

Figure 5 is a Tukey box-and-whisker plot depicting the statistical distribution of hourly PMV values throughout the year. In the graph, each box represents the PMV values distribution for a specific simulation model. Models implementing RES EEMs were omitted, since these measures did not influence the comfort level with respect to the corresponding models without RES. For every box in the graph, bottom and top indicate the minimum and maximum PMV values within which 50% of the hourly data is included. The upper and lower whiskers specify the PMV variability outside the upper and lower quartiles. The dotted horizontal lines represent the Comfort Category limits. Using this type of graph, the most thermally comfortable solutions are represented by compact box-and-whisker elements (which stand for reduced PMV variations), with all values (i.e. the whiskers limits) comprised within the I Comfort Category PMV range.

Based on these considerations, results showed that:

- an overall thermal envelope retrofit (PE5, PE6, from PE9 to PE18) reduced the PMV variability with respect to the RH and shifted the PMV distribution to higher values (i.e. warmer thermal sensations);
- reducing artificial lighting internal gains in thermally efficient models caused an increase in PMV values variability, with values out of the acceptability range (i.e. in IV CC) both towards hot and cold thermal sensations. Packages envisaging an overall lights replacement with LEDs showed the wider distributions;

- system-related measures were the only ones able to maintain I CC PMV values for 50% of the time (i.e. the corresponding boxes are placed between the I CC limits) and to keep acceptable PMV values for the whole year (i.e. the whiskers limit are placed below or nearby the III CC limits). Among these packages, radiant ceiling (measure S1.3) showed the best comfort performances.

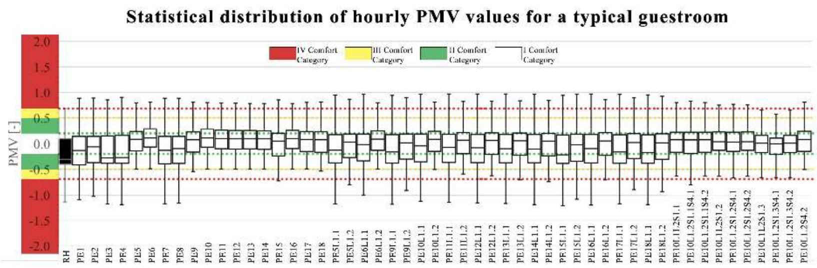

Figure 5 Statistical distribution of hourly PMV values in a typical RH guestroom in annual simulations of RH models implementing packages of envelope, lights, systems and plants EEMs.

In order to relate energy and thermal comfort performances, a comfort-optimal graph was built, as shown in Figure 6. It depicts a scattered plot where $EP_{gl,tot}$ of each simulated package of EEMs is plotted versus the corresponding percentage of time during which PMV values lie within the I CC limits.

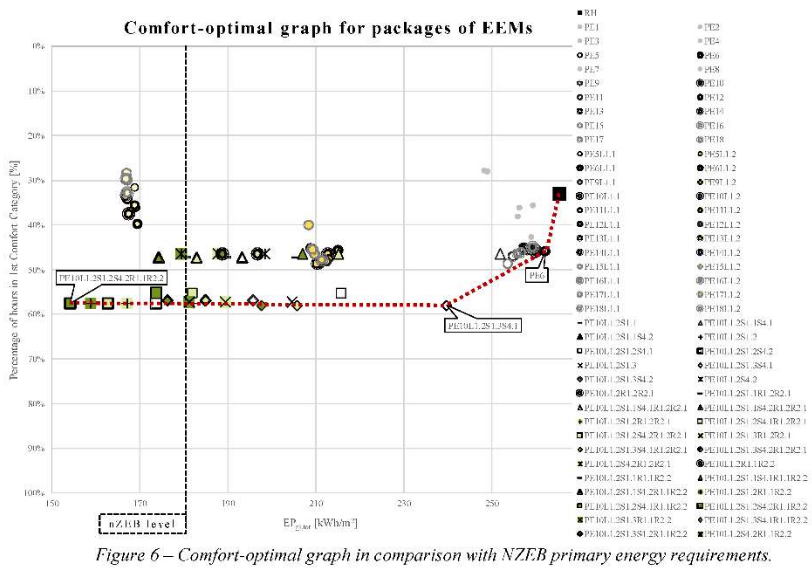

Figure 6 – Comfort-optimal graph in comparison with NZEB primary energy requirements.

The comfort-optimal curve (red dotted line in Figure 6) identifies the comfort-optimal retrofit options as the packages implementing radiant floors/ceilings. Since internal comfort conditions disregard the installation of RES, the range of primary energy values included in the comfort-optimal range is wide. Among them, the lowest value is represented by PE10l1.2S1.2S4.1R1.1R2.2, which was the higher point of the cost-optimal curve (Figure 4). The comparison between Figures 4 and 6 highlights that packages of EEMs complying energy needs and primary energy NZEB requirements have contrasting economic and comfort performances. Packages with lower global costs (i.e. with better economic performance), such as PE PE10L1.2S4.2R1.1R2.2, have lower percentages of PMV values in the I comfort category (i.e. worst thermal comfort performance) and vice-versa. This combined analysis suggests that for a hotel building, where guests' comfort is a priority, financial convenience should not be considered as the only leading parameter to evaluate retrofit options.

CONCLUSIONS

This research was committed to investigate the existing performance gap between cost-optimal and NZEB retrofit options for a Reference Hotel and to the test indoor thermal quality of the considered design solutions. On the one hand, the goal was to inform policy-makers about the existence of technological and/or market barriers towards the market up-take of energy efficiency projects for multi-functional buildings, as hotels are. On the other hand, the study wanted to highlight that financial performances alone are not enough to guide investors towards the most successful retrofit intervention. For better informed investment choices, non-tangible co-benefits such as users' comfort should to be included in the evaluation. A comfort-optimal analysis was the solution here proposed to embody these considerations in the analysis of the RH.

The comparison between NZEB limit values and retrofit options energy performances provided encouraging perspectives for the existing non-residential building stock. Indeed, the implementation of business-as-usual retrofit options allowed the fulfilment of envelope, energy needs and primary energy requirements.

Conversely, the match between energy and financial performances for the simulated retrofit options gave disappointing results. Maintaining the original RH configuration turned out to be the most convenient option. It must be noted that a group of retrofit options showed a consistent energy use reduction together with a very slight increase in global cost with respect to the RH. In this cluster of models, an overall lighting upgrade played the leading role in the drop in energy use. Due to the minor technical interventions and the short-term return of the investment, lights substitution could be a favorite measure among hoteliers. Nonetheless, these retrofit options did not satisfy mandatory nor NZEB energy requirement. Any envisaged solution in line with nZEB limits had a global cost at least 50% higher than the cost-optimal solutions.

Coming to considerations on comfort, the study highlighted that only design solutions including systems-related measures were able to constantly maintain acceptable conditions. Additionally, models implementing packages of EEMs showed contrasting economic and comfort performances. Generally speaking, retrofit options with better economic performances showed worse comfort values.

Generalizing the obtained results, it may be inferred that there is still a significant mismatch between cost-optimal and nZEB retrofit solutions for Italian non-residential buildings. In these buildings, where electricity uses (lighting and appliances) are major responsible of the overall energy performances, the fulfilment of nZEB requirements does not allow to fully exploit the energy saving potential. On the other hand, however, the inclusion of comfort analysis could support the implementation of climatization-oriented retrofit measures, such as systems replacement, as they are able to improve indoor comfort conditions.

SYMBOLOGY

U	Thermal transmittance, W/(m^{2}K)
H'_T	Transmission heat transfer coefficient, W/(m^{2}K)
$A_{sol,est}/A_{sup\ utile}$	Normalized summer effective solar collecting area of glazed elements, ND
$EP_{H,nd}$	Heating energy need index, kWh/(m^2*y)
$EP_{C,nd}$	Cooling energy need index, kWh/(m^2*y)
$EP_{gl,tot}$	Total global primary energy index, kWh/(m^{2}y)
η_H	Heating plant and system efficiency, ND
η_W	Hot water production plant and system efficiency, ND
η_C	Cooling plant and system efficiency, ND
RES_{DHW}	Share of renewable energy sources for DHW production, ND
$RES_{DHW,H,C}$	Share of renewable energy sources for DHW, heating and cooling energy uses, ND
PMV	Predicted Mean Vote, ND
PPD	Percentage of People Dissatisfied, ND

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Paper VII

The role of hotels in shaping a sustainable built environment

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THE ROLE OF HOTELS IN SHAPING A SUSTAINABLE BUILT ENVIRONMENT

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Abstract

Because of its function and nature, tourism sector has the potential to shape cities and citizens. The impact of tourism activities on global CO_2 is around 5% and its reduction is both a technically achievable and a socially beneficial target. For instance, in the hotel sector on one side the use of energy efficiency measures and renewable energy is far below its real potential; on the other side, due to the number of guests they host, hotels have the potential to act as an example of energy responsibility for other industries, as well as for individuals. At the European level, the issue of reducing hotels' energy consumption goes along with the aggressive goals set for the next decades for energy use reduction. In this framework, this paper presents the application of the Europe-wide known cost-optimal methodology to an existing hotel. Indeed, taking into account financial aspects is crucial for the market uptake of sustainable good practices in real, business-driven world. A small-medium mountain hotel located nearby Torino was selected as baseline model for the analysis and a number of energy efficiency measures were defined and implemented in a building energy simulation software. The obtained cost-optimal level of energy performance proved that proper combinations of existing technologies could lead to significant reduction of energy use. However, a critical discussion of the implemented methodology led to the proposal of different evaluation parameters for cost-optimal levels of energy performance for hotels, as a possible solution to catch stakeholders' interest toward green investments.

1_Introduction

Tourism activities, mainly transportation and accommodation, contribute around 5% to global CO_2 emissions, of which 1% specifically related to hotel sector (UNWTO-UNEP, 2008). The relatively small footprint is nevertheless an issue that is being addressed by this major sub-sector of the tourism industry. In a world looking for new models of economic growth and development, adopting sustainable management practices is a condition for survival and success. Over the past several years, the world's leading hotel brands have increased their efforts to respond to environmental issues and invested significantly in going green (Kang et al. 2012). Sustainable practices are now pillars of the Corporate Social Responsibility (CSR) programs that the hospitality industry is increasingly implementing and being viewed as a green hotel is often a desired outcome of a hotel's CSR strategy (Gao and Mattila 2014). Indeed, today's customers are more and more sensitive to ecological matters and greening a hotel is inevitable not just to achieve operational cost savings, but also – and mainly – in order to meet hospitality customers' needs and boost their positive intention and behaviour toward the firm (Han and Kim 2010, Han et al. 2011). Moreover, by trying to answer to green costumers' needs, hotels have the potential to spread eco-friendly behaviours to a wider range of guests and to act as an example of energy responsibility for other industries (UNWTO 2011). Due to the number of clients they receive, they can become a channel for social change (Ryan 2002).
Despite these promising premises, at the current stage hotel sector's use of energy efficiency and renewable energy is far below its real potential and

energy costs still represent a significant part of the operational costs of a tourist accommodation building (RELACS 2010). Particularly, dealing with the small-medium enterprises (SME) sector, poor energy performances are combined with hesitation in investing in green initiatives: even with the opportunities of business success and cost savings, SME hoteliers remain diffident, as they are not convinced of the financial benefits of such investments. Indeed the implementation of green practices requires significant initial investments, for which quantifying returns is often difficult, especially in terms of actual market appreciation (Kang et al. 2012).

In Europe the issue of reducing hotels' energy consumption goes along with the more general goal set by EBPD recast (European Commission 2010), envisaging that from 2021 all buildings newly built or undergoing major renovations will reach the nearly Zero Energy level. Based on the Directive formulation, nearly Zero Energy Buildings (nZEB) are buildings with a very high energy performance and where energy need is covered to a very significant extent by energy from renewable sources. It is task of each EU Member State to define figures for this generic definition, keeping in mind that "energy performance" is the calculated or measured amount of energy needed to meet the energy demand associated with the typical energy use of the building, which include energy use for heating, cooling, ventilation, hot water and lighting. In addition to nZEB policy, EPDB recast specifies that Member States shall set buildings minimum energy performance requirements in view to achieving cost optimal levels, which is the amount of primary energy leading to the minimum life cycle cost. While cost optimality is the current framework regarding the ambition level for renovation of existing buildings and new buildings, the principle of nearly zero-energy buildings will be guiding for new buildings as from 2021. Therefore it is important to secure a smooth and consistent transition of policies and markets from cost optimality to nearly zero-energy buildings (Kurnitski et al. 2011). For the purpose of both nZEB and cost-optimal level calculations, 9 buildings types to be considered are listed by the EPBD recast, including hotels.

In this framework, the IEE co-funded EU project "neZEH – nearly Zero Energy Hotels" (neZEH 2013a) has its place. This 3 years project aims at accelerating the refurbishment rate of existing buildings into nZEB in the hospitality sector and promoting front-runners, focusing on SME hotels. From the operational point of view, the project's scope consists of: providing technical advice to committed hotel owners; demonstrating the profitability, feasibility and sustainability of investments towards nearly Zero Energy through the application of deep retrofit measures to 14 hotels across Europe; promoting the 14 frontrunners; undertaking training and capacity building activities. Reaching these goals set up a number of theoretical issues: indeed, the nearly Zero Energy level, as well as the cost-optimal level of energy performance for hotels, is not put into figures in most of Member States and the typical energy use for this building type is not defined. Following EPBD precepts in terms of energy uses, in a neZEH the typical energy use in hotels can be identified as the energy used for "hosting functions", as proposed by Buso et al. (2014). While different hotels may offer different facilities, entailing a wide gap in the energy needs among buildings with the same general use classification, hosting functions, mainly related to guestrooms, are always present and their energy uses aim at providing comfort conditions to guests and workers. This approach was followed by the neZEH project for setting preliminary benchmark values for hosting functions for new and retrofitted neZEHs in the project partner Member States (neZEH 2013b). Figures regarding primary energy (PE) use for heating, hot water, cooling, lighting and appliances, are shown in Table 1 and were identified as a result of national legislations and literature review.

neZEH partner	Croatia	France	Greece	Italy	Romania	Spain	Sweden
PE indicator - New [kWh/m²y]	77	115	76	71	80	72	134
PE indicator - Refurbished kWh/m²y]	100	150	99	92	104	94	174

Table 1. neZEH benchmarks for hosting functions for new and retrofitted hotels in project partner countries.

Given a general overview, this research aims at presenting and discussing the results of applying the EPBD recast-prescribed cost-optimal methodology to an Italian existing hotel and to verify whether the neZEH benchmarks are achievable and financially convenient. Energy efficiency measures (EEMs) are applied to the selected hotel and their impact on energy consumption and global cost is evaluated. The analysis aims at finding the cost-optimal EEMs and the cost-optimal level of energy performance, considered as a step toward the nearly Zero Energy Hotel target. The obtained results are then critically discussed, particularly questioning whether cost-optimal methodology can give actual support to define the best retrofit strategies for hotels and can seize the extra-benefits (e.g. market appreciation) that going green entails for this kind of business.

2_Method

In this section the steps undertaken in the present cost-optimal methodology exercise, here listed, are extensively described: (1) description of the baseline hotel building; (2) definition of technically feasible EEMs - single measures and packages of measures; (3) energy evaluation through simulations; (4) economic evaluation of the baseline model and the packages of measures.

2.1_Baseline building

A small-medium mountain hotel located in Piedmont (North of Italy) was selected as the baseline model for the cost-optimal analysis. This existing building, built in 1929, was converted into a hotel in the 80's. In 1998 partial retrofit measures, such as boilers replacement, were undertaken. It is a seven-storey building (2 basement levels and 5 floors) in which the following functions are located: the lower level basement houses unconditioned technical rooms and deposits and conditioned function-rooms; the upper basement level hosts laboratories and entertainment areas; the ground floor has a hall, offices and food services (kitchen, restaurant and cafè); the upper floors house 73 guest rooms, with 170 beds in total. The building longitudinal axis is in West-East direction and guestrooms are mainly South oriented, as shown in Figure 1. Coming to figures, total net conditioned area and volume are respectively 5.858 m² and 22.669 m³, the aspect ratio is 0,51 m⁻¹ and the floors dimensions vary from 80x18 m to 80x12 m.

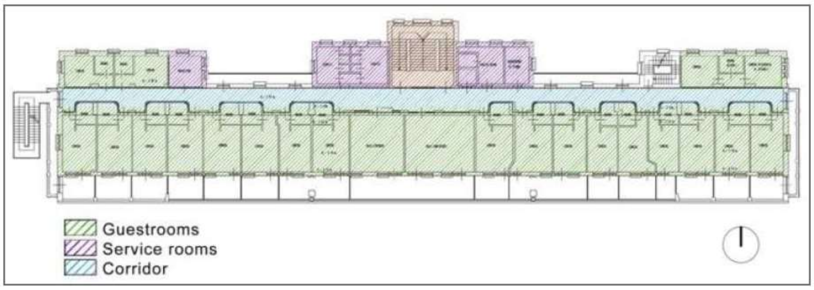


Figure 1. Typical floor plan of the selected existing hotel.

Building plants consist of three gas boilers of 500 kW each, serving the heating system for ground and upper floors with radiators and fan coils as heating terminals, the Domestic Hot Water (DHW) production and three Air Handling Units (AHU) for the climatization of the basement, rarely in use. Finally, envelope thermal properties are summarized in Table 2, in comparison with Italian minimum requirements given by D.L.311/2006 (Italy 2006).

Table 2. Envelope thermal properties of the baseline model.

	Baseline Building U [W/m²K]	Standard Requirements U [W/m²K]
External wall	1,09	0,33
Roof	0,97	0,29
Windows	1,95	2,00

2.2_Energy Efficiency Measures (EEMs)

Technically feasible retrofit possibilities of the baseline model were defined in order to achieve energy savings through the improvement of the building envelope properties and of the building systems efficiency and through the exploitation of Renewable Energy Sources (RES). As recommended by the European Commission (2012), single EEMs were combined in packages in order to investigate possible synergy effects. Table 3 lists the single Energy Efficiency Measures and in Table 4 the 13 resulting packages of measures are presented.

EEMs type	Code	Intervention	U [W/m²K]
Envelope	EEM1	External walls insulation (from internal side)	0,32
	EEM2	Walls to unheated insulation	0,32
	EEM3	Roof insulation (from internal side)	0,24
	EEM4	Windows substitution	0,90
Plants	EEM5	Substitution of gas boilers with condensing boilers	
	EEM6	Substitution of heating terminals with radiant ceiling	
	EEM7	Installation of mechanical ventilation system	
RES	EEM8	Installation of Solar Thermal (ST) Panels (255 m², 100% DHW need)	
	EEM9	Installation of Solar Photovoltaic (PV) Panels (153 m², 19 kWp)	

Table 3. Single Energy Efficiency Measures (EEMs) applied to the baseline model.

Code	Intervention
P1	EEM1 + EEM2 + EEM3 + EEM5
P2	EEM1 + EEM2 + EEM3 + EEM5 + EEM6
P3	EEM1 + EEM2 + EEM3 + EEM4
P4	EEM1 + EEM2 + EEM3 + EEM4 + EEM5
P5	EEM1 + EEM2 + EEM3 + EEM4 + EEM5 + EEM6
P6	EEM1 + EEM2 + EEM3 + EEM5 + EEM8
P7	EEM1 + EEM2 + EEM3 + EEM5 + EEM6 + EEM8
P8	EEM1 + EEM2 + EEM3 + EEM7 + EEM9
P9	EEM1 + EEM2 + EEM3 + EEM5 + EEM7 + EEM9
P10	EEM1 + EEM2 + EEM3 + EEM5 + EEM8 + EEM9
P11	EEM1 + EEM2 + EEM3 + EEM4 + EEM5 + EEM8
P12	EEM1 + EEM2 + EEM3 + EEM4 + EEM7
P13	EEM5 + EEM8

Table 4. Packages of EEMs applied to the baseline model.

2.3_Energy Evaluation

The energy performances under investigation are those prescribed by the Italian D.Lgs 192/2005. It transposes the EPBD (European Commission, 2002) to the Italian context and requires to calculate the amount of primary energy necessary for maintaining the whole building at the standard comfort condition during the heating season (i.e. t_{indoor}=20°C). Building configurations were modeled in Docet energy simulation software. The Docet version used was based on the Italian standard UNI/TS 11300 1-2 (CTI 2012, 2008) simplified calculation method. Developed by the national research institutions ITC-CNR and ENEA, it was expressly intended to easily provide Primary Energy (EP_{gl}) values to be used in the Italian Energy Performance Certificates (EPCs). At the time of this research, the Italian EP_{gl} only took into account energy uses for heating and DHW, therefore Docet software only provided information about the delivered energy and primary energy used for these functions (electricity uses for lighting, appliances and cooling are not simulated).

Italian regulation for minimum primary energy requirements and EPCs was updated in October 2015. Now EPCs have to rate, for non-residential buildings, energy uses for lighting, cooling and elevators for all non-residential buildings.

2.4_Economic Evaluation

Aim of the present work is to define the cost-optimal level of energy performance for an existing hotel building. In accordance with EPBD recast, the cost-optimal framework methodology is based on a comparative methodology framework that builds on the global cost (C_G), or net present value, method. Input data for global cost calculation are shown in formula 1:

$$C_G(\tau) = C_I + \Sigma_J * \left[\Sigma_{i=1}^{\tau} \left(C_{a,i}(j) * R_d(i) \right) - V_{f,\tau}(j) \right], \quad (1)$$

where $C_G(\tau)$ represents the global cost referred to starting year τ_0, C_I is the initial investment cost, $C_{a,i}(j)$ is the annual cost for component j at the year i (including running costs and periodic or replacement costs), $R_d(i)$ is the discount rate for year i, $V_{f,\tau}(j)$ is the final value of component j at the end of the calculation period (referred to year τ_0). The discount rate R_d is used to refer the costs to the starting year; it is expressed in real terms, hence excluding inflation.

For the baseline model and for each model implementing EEMs all the data were defined and the global cost was calculated. The calculation period was set as 30 years; 4% discount rate was used; investment costs were taken from Piedmont Price List 2011 (Regione Piemonte 2011); replacement and maintenance costs were derived from EN 15459:2007 Appendix A (CEN 2007); energy costs were calculated by applying to Docet simulation results the following energy tariffs: natural gas cost = 0,091 €/kWh; electricity cost = 0,2 €/kWh.

3_Results

3.1_Energy Evaluation

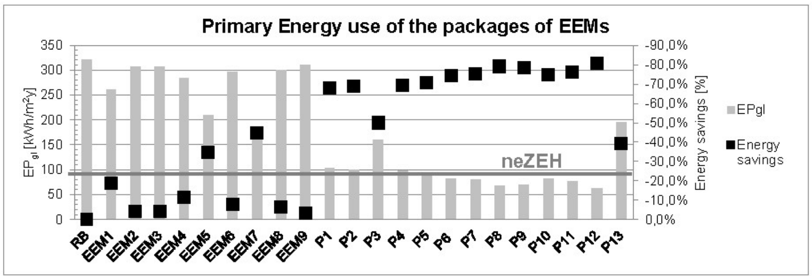
As a first step, the theoretical delivered and primary energy uses of the baseline model were defined through simulation. Results, presented in Table 5, show the building energy performance related to the typical energy use of the building for heating and DHW production.

Table 5. Simulated delivered and primary energy use of the baseline model.

Energy source	Energy use	Delivered energy [kWh/m²]	Primary energy [kWh/m²]
Gas	Heating	298,8	299,3
Electricity		0,2	
Gas	DHW	20,9	20,9
EP_{gl}			320,2

By applying the defined EEMs and packages of EEMs to the RB, the achievable energy savings are obtained. In Figure 2 the primary energy needs of the several design options are shown in parallel with the related energy savings and with the neZEH benchmark for retrofitted hotels. As expected, single energy efficiency measures were less effective in reducing the building energy use than packages of measures, in which superposition of effects and synergies allowed to reach savings always higher than 40%. The most efficient EEMs (savings > 30%) are related to the plant system (EEM7 and EEM5). Regarding EEM9, PV panels installation, the evaluated savings are the lowest because of the energy uses taken into account in the simulation (no electricity): positive effects of PV panels can be seen in packages where they are coupled with the mechanical ventilation system (P5, P6). It is also worth noting that 7 packages of measures gave primary energy results lower than

Figure 2. Primary energy use for heating and DHW of the simulated models implementing EEMs and packages of EEMs.

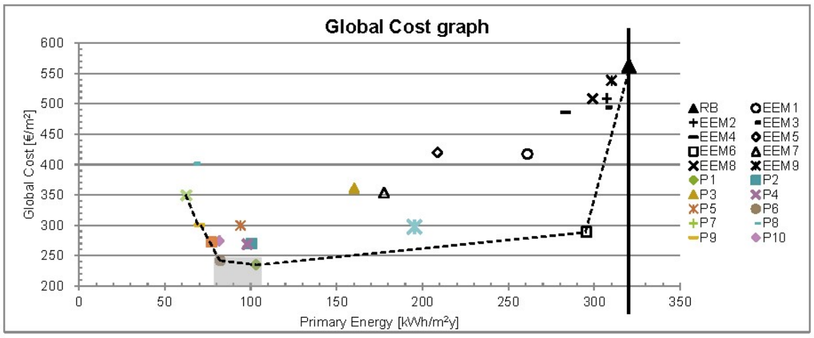


Italian neZEH benchmark (< 92 kWh/m²y). The highest energy savings (81%, EP_{gl} = 63 kWh/m²y) were obtained by P12, where heat losses are minimized by insulated envelope and windows and ventilation losses are reduced thanks to the mechanical ventilation system. However, neZEH benchmarks consider all energy flows in the primary energy indicator, while the Italian regulation only takes into account energy for heating and DHW production. Therefore, the neZEH benchmark will not be considered in the cost-optimal graph.

3.2_Economic Evaluation

The performed energy analysis was functional to the definition of the cost-optimal level of energy performance of the selected hotel building. Primary energy results for EEMs and packages of measures were plotted versus the calculated global costs, as shown in Figure 3. In the graph, the black vertical line represents the EP_{gl} of the reference building, the dotted black line draws the cost curve and the grey area highlights the cost-optimal level of energy performance, i.e. the primary energy use of the EEMs that minimize the global cost. Results in Figure 3 highlight that the cost-optimal level for the selected building is reached by 2 options. The lowest global cost is obtained by P1 (235 €/m² and 103 kWh/m²y), implementing to the baseline model opaque envelope thermal insulation and new condensing boilers. P6, where ST panels are added to the features of P1, provides better energy performance (82 kWh/m²y) for a slightly higher global cost (242 €/m²). The graph also provides a rationale for defining the best intervention to invest in. On one hand, packages with similar EP_{gl} may have different global cost (C_G), as exemplified for instance by EMM6 (EP_{gl} = 296 kWh/m²y; C_G = 289 €/m²) and EEM8 (EP_{gl} = 299 kWh/m²y; C_G = 508 €/m²). On the other hand, packages with very similar global cost can differ in energy performances. P5 (EP_{gl} = 94 kWh/m²y; C_G = 300 €/m²) and P13 (EP_{gl} = 195 kWh/m²y; C_G = 297 €/m²) are an example.

Figure 3. Global Costs of the EEMs and packages of EEMs represented as a function of primary energy consumption.



4_Discussion

A cost-optimal exercise was performed for an Italian hotel building in order to test the applicability of general EU disposition regarding nZEB and cost-optimality in a national context and to a specific building type. Results presented above are here interpreted and discussed.

The energy-related outcomes seem to confirm that, also in the case of hotels, current technologies related to energy savings, energy efficiency and renewable energies are sufficient to reach, in combination, a suitable target for nearly zero-energy buildings (Ecofys et al. 2013). Nevertheless sound evidences of this statement cannot be presented because of the discrepancy between the energy flows included in primary energy calculation in the neZEH project benchmarks and those considered in the Italian EP_{gl}. This mismatch leads to consider, in the Italian application of neZEH benchmarks, only a fraction of the typical energy use of the building. The issue here raised is consistent with the problem of heterogeneous definitions of nZEB implemented at the national level reported by Jurnitski et al. (2014) and may be partly solved by the new Italian dispositions regarding minimum energy requirements and energy performance certificates. Next steps of the present study should update the method presented in section 2.3 Energy Evaluation.
Another aspect asking for further investigation is whether the typical primary energy use of the building is the proper parameter to be taken into account for energy and cost-optimal evaluation for hotels, and for multipurpose buildings in general. In hotels the energy use for maintaining occupants' comfort is complementary to energy uses for maintaining the quality of offered services. Indeed, for each multipurpose building use, offered services are the characterizing element and their energy consumption is very dependent on the service quality, which in turn is proportional to the economic advantages deriving from them. Therefore, from the private investors' standpoint, the whole (typical + extra) building energy use may be considered when economic evaluations of different retrofit design options are compared.
Dealing with the economic evaluation of buildings retrofit, the cost-optimal methodology, used at national level to define the most economically sustainable minimum energy requirements, may not be satisfactory for the private investors' perspective. At the current stage, only reduced running cost and higher final value of the building are considered as assets for implementing retrofit measure. For boosting green private investments, extra benefits deriving from the renovation process, such as improved image of the building, new market positioning, increased guests comfort and satisfaction, should be included, with appropriate indicators, in the calculation method. Examples of studies addressing the link between green investments and the quantification of not straight tangible returns flourish in the hotel sector, where, for instances, guests' willingness to pay for sustainable lodging has been deeply investigated (Han et al. 2009, Kang et al. 2012). In hotel buildings, the impact of benefits on the hoteliers' finances comes from workers and guests' satisfaction and from the building performances, tackling all at once comfort, health, market appreciation and residual value issues.

5_Conclusions

The cost-optimal analysis applied to an Italian existing hotel pointed out that packages of energy efficiency measures have the potential to lead to the energy performance requirements proposed for nearly Zero Energy Hotels and that cost-optimal level of energy performance is able to significantly reduce the building primary energy use (-74%). These findings were critically discussed in view of reaching a realistic and effective energy and economic evaluation for hotel building type: alternatives to the energy use prescribed for calculations by the EPBD recast and to the variables to be included as co-benefits in the global cost methodology were introduced.

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Paper VIII

A future nearly Zero Energy Hotel in Italy

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Articles

A future nearly Zero Energy Hotel in Italy

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The paper presents the refurbishment project of one of the Italian pilot cases of the European neZEH project, the Residence L'Orologio in Turin. The provided information resulted from the energy audit and the feasibility study, currently in progress, aiming to guide the hotel owners in their choices.

Keywords: neZEH, nZEB, hotel, refurbishment project, energy efficiency measures.

Introduction

The case study proposed in this paper aims at demonstrating the feasibility and sustainability of a refurbishment project of a small-medium hotel. This is also one of the main goals of the IEE funded project neZEH[1] and, indeed, the presented hotel, the Italian Residence L'Orologio, is included in the long list of the thirteen European pilot projects that will run for the nearly Zero Energy goal in their businesses across seven countries.

The information derived from the energy audit of the Residence L'Orologio were used to structure this paper. Based on the current building features, the building model was implemented in an energy simulation software and retrofit interventions were simulated and evaluated by applying the cost-optimal methodology.

The Hotel and its context

The Residence L'Orologio is an urban hotel located in a central area of Turin, in Piedmont Region. The geographical location is representative of the Italian Middle Climatic Zone (HDD=2617), such as classified by Tabula project [1]. The specific location of the building, a densely built and historical part of the city, exemplifies the challenges of renovating the building stock in Italy.

This apartment building built at the beginning of 20th century was refurbished and converted into a hotel about ten years ago; the renovation process was started in 2003 by Talaia family, current owners and managers of the Residence. It is worth noting that, because of its historical features, the building is subjected to some constraints, to be considered during the renovation

1 Nearly Zero Energy Hotels (neZEH) is a three years long project supported by the Intelligent Energy Europe (IEE) program started in April 2013, involving a consortium of seven European Countries (Croatia, France, Greece, Italy, Romania, Spain, Sweden) and ten partners. The project aims at accelerating the refurbishment rate of existing buildings into nZEB in the hospitality sector and promoting the front-runners. Focusing particularly on the SME hotels. www.nezeh.eu

process. Particularly, the main façade cannot be insulated neither from the outside, because of aesthetical reasons, nor from the inside, because of standard minimum guestroom dimension to be maintained.

The building has a rectangular plan, developing in six floors above ground and in a half-basement area (**Figure 1**). Not the whole building area is occupied by the hotel: the top-floor hosts two private apartments, independent from it. Residence L'Orologio offers twenty guestrooms, each of them fully supplied with appliances such as fridge, dishwasher, electric oven, microwave, electric stove, washing machine and TV. Indeed, this business mainly relies on guests' long-term stays, which requires the guestrooms to be very similar to small apartments in terms of internal layout and equipment. The extra facilities offered by the Residence are a small gym, a kitchen for the staff and a children playroom, all located at the half-basement. The main data about the hotel are displayed in **Table 1**.

Original building envelope and energy system

Residence L'Orologio presents a very traditional structure with load bearing masonry walls. During the first refurbishment of the building, ten years ago, no further insulation was added because their thermal properties were good enough according to the national minimum requirements in effect at that time [2]. Nonetheless, the walls transmittance ($U_{wall,hotel}$ = 1.12 W/m²K) is far below the limit U-value currently in force in Piedmont ($U_{wall,standard}$ = 0.33 W/m²K [3]). On the contrary, all the windows were substituted with the most up-to-date solution in 2005: windows with double-pane and wooden frame ($U_{window,hotel}$ = 2.5 W/m²K). Again, the thermal performance of windows are below the current standards expectations ($U_{window,standard}$ = 2.00 W/m²K [3]).

Dealing with plants, the building is now heated by two condensing boilers powered by natural gas (rated output 84 kW), also used for Domestic Hot Water (DHW) production. The DHW loop also includes an accumulation tank of 300 litres, where water is maintained at the temperature of 46°C. A chiller (cooling capacity 97 kW) is installed for the cooling system. Two-pipes fan coil units, placed in the false ceiling, are the terminals of the heating and cooling system. At present, the building does not have a mechanical ventilation system (except for exhaust air systems in bathrooms and kitchens) and it does not use any on-site renewable energy source.

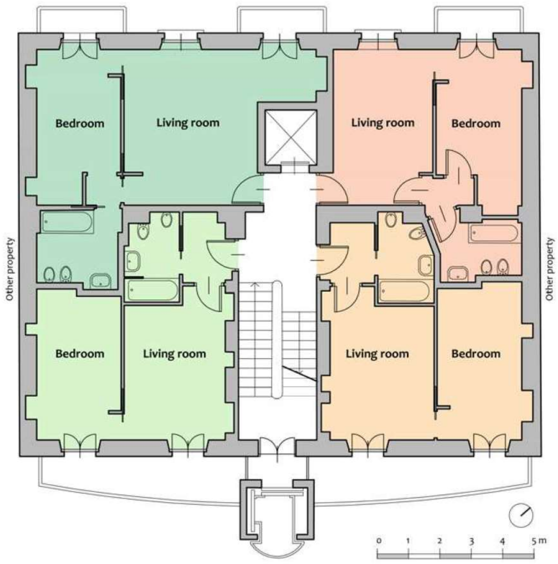


Figure 1. Typical floor.

Table 1. Hotel's main information.

Name Residence L'Orologio
Location Corso Alcide De Gasperi 41, Turin
Type of hotel Urban
Owner Talaia family
Manager Stefania Talaia
Floor area 1 138 m² *(heated area)*
Floors 6 (one half-basement area)
Guest rooms area 874m²
Guest rooms 20
Guest beds 78
Offered facilities Gym, kitchen for the staff, (children playroom)

Articles

In terms of energy use management, a number of energy saving measures are installed. All rooms are supplied with key-card and windows' opening sensors communicating with the cooling system.

Current energy consumptions

The energy audit performed within the neZEH project allowed to obtain and compare real and simulated energy uses for Residence L'Orologio. On one side, the actual energy use of the hotel, derived from energy bills, were extrapolated for the past two full years (2013, 2014). On the other side, the information collected about the building physical (envelope, plants, etc.) and operational (occupancy, equipment schedules, etc.) features enabled the authors to model the building in SEAS[2] energy simulation software. In case of unknown operational details, reference was made to Italian standards (e.g. minimum ventilation rates, derived from Italian standard UNI 10339 [4]). The simulated delivered energy uses are in line with the actual energy uses, as shown in **Table 2.** Primary energy consumption was calculated by applying to the annual delivered energy results the Italian primary energy factors for natural gas and electricity (1 kWh_{gas} = 1 kWh_{PE} [5]; 1 kWh_{el} = 2.174 kWh_{PE} [5])[3].

Considering that different hotels may offer different facilities, the neZEH Project approaches to the problenm by dealing only with the hotels' energy use for the "hosting functions" (guests' rooms, reception hall, offices, bar and restaurant, meeting rooms), as defined in [6]. Therefore, in addition to the primary energy consumptions for the whole building, energy uses for the hosting functions are displayed. They will be the focus for the next steps of the study.

Toward the energy retrofit: defining Energy Efficiency Measures

The above information was the starting point to draft building energy retrofit hypothesis for the hotel. The existing building was taken as the baseline model to which technically feasible Energy Efficiency Measures (EEMs) were applied via simulations. Bespoke options were considered by taking into account energy audit results, context, building typology and, of course, owners' point of view. Blending EEMs, packages of retrofit interventions (summarized in **Table 3**) were proposed.

Table 2. Energy consumptions of the building.

		REAL		CALCULATED			
		DELIVERED ENERGY		DELIVERED ENERGY		PRIMARY ENERGY	
SOURCE		2013	2014	Whole building	Hosting functions	Whole building	Hosting functions
Natural gas	kWh_{th}	160 694	142 715	152 035	152 035	152 035	152 035
	kWh_{th}/m^2	141	125	134	134	134	134
Electricity grid	kWh_{el}	96 324	80 443	81 703	69 279	177 622	150 612
	kWh_{el}/m^2	85	71	72	61	156	132

Table 3. List and description of the packages of retrofit interventions.

EEM	Interventions													
	1	2	3A	4A	3B	4B	5B	6B	1C	2C	1D	2D	3D	4D
Water saving devices	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓
District heating					✓	✓	✓	✓		✓				
Solar thermal system			✓	✓					✓					
Wall insulation - 10 cm				✓		✓								
Wall insulation - 23 cm								✓						
Windows substitution				✓		✓		✓						
Stand-by reduction	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Induction cookers		✓	✓	✓	✓	✓	✓	✓				✓	✓	✓
LED lights		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Photovoltaic system							✓	✓					✓	✓

2 Simulation and energy diagnosis software developed by the Department of Energy Engineering, Systems, Land and Construction (DESTEC) at the Pisa University in collaboration with ENEA.

3 The Italian primary energy factor used in this paper were modified by D.M. 26.06.2015, valid from 1st October 2015. Since the study was carried on before this date, the new factors were not used.

Energy and Economic evaluation of the retrofit options

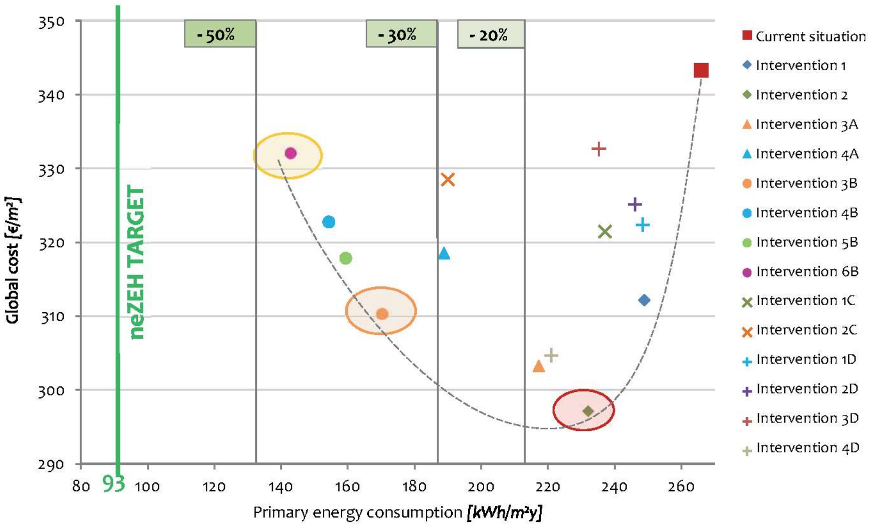
The energy and economic convenience of the proposed retrofit interventions was evaluated by applying the EU-suggested cost-optimal analysis [7], aiming to define the amount of typical primary energy use (i.e. energy use associated with a typical use of the building) leading to the minimum life cycle cost. The cost-optimal framework methodology builds on a comparative methodology framework that is based on the global cost (C_G) method [8], therefore for the baseline model and for each model implementing EEMs all the required input were defined and the C_G was calculated. The calculation period was set as twenty years; 3% discount rate was used; investment costs were taken from Piedmont Price List 2015 or derived from market estimations; replacement and maintenance costs were derived from EN 15459:2007 Appendix A [7]; energy costs were calculated by applying to SEAS simulation results the following energy tariffs: natural gas cost = 0.063 €/kWh; electricity cost = 0.190 €/kWh.

Graph 2 shows the results of the cost-optimal analysis. Primary energy results for retrofit interventions are plotted versus the calculated global cost and vertical lines points out different reduction targets up to the most ambitious one, the Italian benchmark for nearly Zero Energy Hotels defined by neZEH project [5].

The study shows intervention 2 as the cost-optimal retrofit option. However, despite the higher global cost, intervention 3B is a valuable proposal as well, able to reach much higher primary energy savings (- 36% with respect to the baseline model).

Moreover, thinking of an on-going retrofit process, the building could implement EEMs during the years by starting from intervention 2 and going up to the intervention 6B (nearly 50% of primary energy savings). The **intervention 2** would allow the building to save more than 4 000 € per year by implementing simple EEMs. They could be the first improvements for the Residence. By connecting the hotel to the district heating system (**int. 3B**) cost savings are similar, but the higher initial cost is balanced by primary energy savings: 36% of reduction due to the high percentage of RES used to produce this thermal energy. Thus, owners could decide to proceed with the refurbishment by installing photovoltaic panels (**int. 5B**) reducing primary energy to 40%. The last intervention (**int. 6B**) was calculated with the aim to investigate on the best performances of the building by mixing all compatible EEMs.

With regard to the neZEH benchmark, none of the feasible retrofit intervention was able to reduce the primary energy use to the desired target. However, it



Graph 2. Cost optimal analysis.

must be noted that the high electricity consumptions of the building are mainly due to the fact each guestroom is fully supplied with appliances, which is not the case of a standard hotel. By excluding these "extra-consumptions", the best achievable primary energy index (int. 6B) decreases from 143 kWh/m²y to 112 kWh/m²y, getting closer to the benchmark. Major interventions, usually related to an overall building reinvestment and remodelling, would allow making the benchmark reachable.

Moreover, the peculiarities of the structure make neZEH target too ambitious. The most evident "real life" constraints for the implementation of retrofit measures are related to the building envelope. The façade insulation is not a suitable measure because of the high cost and the possibility to operate only in the south one and the windows substitution is considered just a theoretically feasible EEM (the potential energy performance improvement achieved does not justify the high investment cost).

Lessons learned

Simulation results pointed out that none of the technically feasible and admissible retrofit intervention is able to reach the target, even if they could lead to halve the current primary energy consumption. These findings are at first sight disappointing for the purpose of the project. Nonetheless on one side they might be the starting point for a review of the proposed benchmarks based on "on-field" experience. On the other side, is must be noted that all interventions were proposed based on the hotelier's needs and plans, which did not include a major renovation. In case of overall building reinvestment, more invasive interventions could have been proposed, making the neZEH target easier to meet.

The economic evaluation of the retrofit interventions, compared in terms of global cost, pointed out that the cost-optimal level of energy performance for Residence L'Orologio is very far from the higher achievable energy performance indicating that financial support by renovation grants or some other incentives would be required in order to realize the energy saving potential. Nonetheless, programming a process of implementation of retrofit measures can be a solution to reach the highest energy performance by distributing the economical efforts year by year. ■

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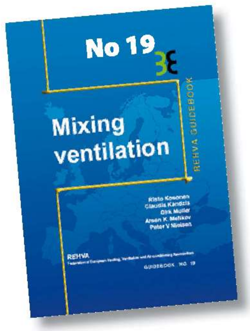
See the complete list of references of the article in the html-version at www.rehva.eu -> REHVA Journal.

REHVA Guidebook on
Mixing ventilation



Mixing ventilation is the most common ventilation strategy in commercial and residential buildings. Introduced will be the new design guide that gives overview of nature of mixing ventilation, design methods and evaluation of the indoor conditions.
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Paper IX

Energy Efficiency and Financial Performance of a Reference Hotel – Proposing a Global Cost-Benefit Analysis

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Energy Efficiency and Financial Performance of a Reference Hotel - Proposing a Global Cost-Benefit Analysis

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Abstract

Academic literature suggests a positive relationship between environmental and financial performance in property investments: in addition to the energy savings related to the building renovation, co-benefits can be reaped, ranging from being healthier to providing lower ownership risk. In this context, the paper describes the EU prescribed cost-optimality calculation performed for a hotel building and proposes an experimental revised version on the cost-optimal methodology, in which the co-benefits of energy retrofit are assessed and included in the calculation. An Italian existing Reference Hotel (RH) was selected as baseline model for the cost-optimal analysis. A number of Energy Efficiency Measures (EEMs) and packages of EEMs for the building envelope were applied to the RH, for which energy performances were assessed through a dynamic energy simulation software. Firstly, primary energy consumptions and global costs of the packages of EEMs were derived to identify the cost-optimal configuration from a financial point of view. The second step of the work dealt with the definition of a revised version of the formula for global cost. The proposed "global cost-benefit" formula was then applied to all the retrofit options. Results showed that including co-benefits can significantly reduce the global cost of retrofit projects and can transform the cost-optimal methodology in a useful tool for modifying investors' perception of the financial convenience of retrofit interventions.

Keywords - building energy retrofit; cost-optimality; global cost-benefit; reference hotel

1. Introduction

Energy efficiency has gained the floor in global policies as a key resource for economic and social development, procuring tangible and intangible benefits to many different stakeholders [1]. However, in the building sector energy efficiency potential remains mostly unexploited [1]. Indeed, in order to develop a lively market of energy efficiency investments, key decision makers have to have a clear understanding of the wide spectrum of improvements that energy efficiency upgrades may bring, as pre-condition for their voluntary involvement. A wide sample of academic literature and public reports lists, analyses and attempts to quantify such benefits, whose positive effects can be seen both at macro and micro economic scale [1, 2, 3].

Monetization of non-tangible benefits related to energy efficiency in buildings, here named co-benefits, is a complex task that requires deep understanding of countries' specific markets. Because of their inner complexity, co-benefits are currently not included in the cost-optimal methodology, recommended by the EPDB recast for the definition of minimum energy requirements in buildings in EU Member States. The methodology, by defining as "cost-optimal" the energy performance level which leads to the lowest cost during the building estimated economic lifecycle, has also the potential to become a useful decision making tool for stakeholders at the preliminary design stage. An increase in investments in energy efficiency may pass through this formula.

First proposals to include co-benefits in the well-established cost-optimal methodology can be found in [4] and [5]. The present paper follows these footsteps and focuses its attention on the inclusion in the global cost formula of co-benefits appreciated by private investors, with a specific focus on hotel businesses. Indeed, studies [6] reveal that the role of co-benefits in the decision of going green is a major issue in the hotel sector. Particularly interesting for this specific building category is the inclusion of increased guests' willingness to pay among the co-benefits. Green initiatives in hotels are perceived as ancillary services, for which guests may decide to pay more [7]. It must be specified that in the context of the hospitality sector, promoting a green image in strongly linked to green certifications. These hotel-related green certifications, such as Green Globe, Nordic Swan and Green Key, most often consider low energy use as one evaluation criteria of many and with no limit value to comply with. On the contrary, particular attention is paid to the use of eco-friendly materials [8].

In the next paragraphs, the evaluation of energy and economic performance of several retrofit options for the envelope of an Italian existing Reference Hotel (RH) is described. Capital intensive EEMs for passive strategies of retrofit were prioritized as they are the first step to increase energy efficiency in the context of an overall building renovation and reinvestment. First, the traditional cost-optimal analysis was performed. The second step entailed the definition and the hypothetical quantification of co-benefits to be included in a revised formula of global cost-benefit. Finally, the effect of this new formula was tested on the RH with respect to the previous analysis and different scenarios of co-benefits inclusions were compared and discussed.

2. Case study

The Italian existing Reference Hotel (RH) defined in [9] was used as baseline model for the study. The designated RH is a family-owned, 3-star, medium size hotel, open all year and built in an urban context in the Middle Climatic Zone (Turin, HDD=2617) between 1921-1945. Such a combination of features is statistically relevant in the Italian hotel buildings stock and it depicts a typical private investor's situation, with high potential for business improvements.

The building has a North-South oriented rectangular plan, developing in 4 floors above ground and in an half-basement area, where the extra facilities are located. With a total heated area of 1700 m^2, it offers to guests 49 rooms, a fitness area and a breakfast hall. The envelope thermal performance, focus of the present work, are summarized in column 2 of Table 1.

The hotel is heated by a condensing boiler powered by natural gas, with radiators as terminals units. Two condensing boilers are dedicated to domestic hot water production. A chiller is installed for cooling and the related terminals are two-pipes fan coils. Neither mechanical ventilation nor exploitation of on-site renewable energy sources are present.

Hotel's occupancy and operation values were taken from UNI 10339:2005 and EN 15232:2007, their schedules from [10]. Comfort conditions were set according to Comfort Category I defined by EN15251:2007.

In order to evaluate the energy performance of the so-defined virtual reference building, a simulation model was built and run in Energy Plus.

3. Method

a. Cost-optimal analysis

Applying the cost-optimal methodology requires three main stages, detailed in the followings for the specific case study.

Stage 1: definition of retrofit options. Energy Efficiency Measures (EEMs) and Packages of EEMs were applied to the RH envelope. Two different retrofit strategies were followed in parallel: the first foresees the use of standard materials and techniques to achieve the required energy performances levels (e.g. EPS insulation and PVC windows); the latter uses eco-friendly materials, such as recycled wood fiber insulating panels and windows with frames in local wood, to fulfil the same requirements. The implementation of eco strategies seeks to comply with hotels green certifications requirements. Coming to energy requirements, two levels of minimum performances for the envelope elements were established based on figures set by the Italian Decree "Requisiti Minimi" 26-06-2015. Table 1 presents the limit values for EEMs. Table 2 lists the ten resulting packages of measures.

Table 1. Energy Efficiency Measures (EEMs) applied to the baseline model

Envelope component	Perf. Level RH	Perf. Level 1	EEM Code	Perf. Level 2	EEM Code
External wall	U=1.1 W/(m²K)	$U \leq 0.30$ W/(m²K)	E1.1	$U \leq 0.26$ W/(m²K)	E1.2
	U=0.8 W/(m²K)		E1.1eco		E1.2eco
Ground floor	U=2.0 W/(m²K)	$U \leq 0.30$ W/(m²K)	E2.1	$U \leq 0.26$ W/(m²K)	E2.2
			E2.1eco		E2.2eco
Roof	U=0.7 W/(m²K)	$U \leq 0.25$ W/(m²K)	E3.1	$U \leq 0.22$ W/(m²K)	E3.2
			E3.1eco		E3.2eco
Windows/ doors	U_w=4.9 W/(m²K)	$U \leq 1.80$ W/(m²K)	E4.1	$U \leq 1.40$ W/(m²K)	E4.2
	U_w=5.7 W/(m²K)				
	U_w=3.8 W/(m²K)		E4.1eco		E4.2eco
Shadings	-	overhangs	E5.1	automated blinds	E5.2

Table 2. Packages of EEMs applied to the baseline model

Code	EEMs included
PE1/PE1eco	E1.1(eco) + E2.1(eco) + E3.1(eco)
PE2/PE2eco	E1.2(eco) + E2.2(eco) + E3.2(eco)
PE3/PE3eco	E4.1(eco) + E5.1
PE4/PE4eco	E4.2(eco) + E5.1
PE5/E5eco	E1.1(eco) + E2.1(eco) + E3.1(eco) + E4.1(eco)
PE6/PE6eco	E1.2(eco) + E2.2(eco) + E3.2(eco) + E4.2(eco)
PE7/PE7eco	E1.1(eco) + E2.1(eco) + E3.1(eco) + E5.1
PE8/PE8eco	E1.2(eco) + E2.2(eco) + E3.2(eco) + E5.1
PE9/PE9eco	E1.1(eco) + E2.1(eco) + E3.1(eco) + E4.1(eco) + E5.1
PE10/PE10eco	E1.2(eco) + E2.2(eco) + E3.2(eco) + E4.2(eco) + E5.1

Stage 2: Energy Evaluation. EEMs and package of EEMs were implemented in the RH Energy Plus baseline model in order to evaluate their impact on primary energy uses.

Stage 3: Economic evaluation. As prescribed by the EU standard EN 15459:2007, the global cost (C_G) was calculated for the baseline scenario and for each retrofit option by applying equation (1):

$$C_G\,(\tau) = C_I + \sum_j * \left[\sum_{i=1}^{\tau} \left(C_{a,i}\,(j) * R_d(i)\right) - V_{f,\tau}\,(j)\right], \quad (1)$$

where $C_G\,(\tau)$ represents the global cost referred to starting year τ_0, C_I is the initial investment cost, $C_{a,i}$(j) is the annual cost for component j at the year i (including running costs and periodic or replacement costs), R_d (i) is the discount rate for year i, $V_{f,\tau}$(j) is the final value of component j at the end of the calculation period (referred to year τ_0). The discount rate R_d, expressed in real terms (i.e. excluding inflation), is used to refer the costs to the starting year.

Being the calculation performed from a microeconomic point of view, Italian VAT and taxes were included in the calculation of investment and running costs. The calculation period was set as 20 years; 4% discount rate was used; investment costs were taken from Piedmont Price List 2015; replacement and maintenance costs were derived from EN 15459:2007; energy costs were calculated by applying to Energy Plus simulation results the following energy tariffs: natural gas cost = 0,08 €/kWh; electricity cost = 0,23 €/kWh.

b. Identification of co-benefits

The present paper focuses its attention on the inclusion in the global cost formula of co-benefits appreciated by private investors. The identified co-benefits can be grouped in initial, running and final value benefits. They are listed, briefly justified and explained in the followings. Being the monetization of co-benefits a currently pending big challenge, too much context-dependent to be summarized in exact figures, the paper gives different options of monetization for each co-benefit.

Incentives (I). As explained by [5], the inclusion of incentives in the cost-optimal analysis of specific buildings can play an important role in investors' decision making process. Here a null and two positive amount of incentives are considered, based on Italian dispositions. Benefits are quantified as a percentage of the initial investment costs and they are accounted as a negative value in the revised cost-optimal formula.

Reduced sick leave (SL). Academic literature reveals a strong link between indoor air quality and Sick Building Syndrome [11]. This impact can be quantified by relating the economic value of a day of sick leave and the building ventilation rate, as proposed by [12]. In the present study EEMs do not modify the ventilation rate, therefore sick leave is assumed as constant and is excluded from benefits calculation.

Productivity (P). It has been widely verified that indoor environmental quality (IEQ) affects employees' productivity. As summarized in [13], productivity has a clear link with indoor air temperature and ventilation rates. Being ventilation constant among the considered retrofit options, in this work only the effect of indoor air temperature was considered. The equation statistically determined by [14] was used to define the variation in productivity. The obtained variation was related to the average hourly salary of an Italian employee (Salary = 16.83€/h), derived from Istat, the Italian institute for statistics. Only thermal zones dedicated to employees work (reception and office) were considered. Depending on indoor air temperature, productivity variation may be a positive (i.e. a cost) or a negative value (i.e. a benefit) in the CB_G formula.

Increased Service Price (sp). Several studies investigated the relation between green hotels costumers' Willingness to Pay (WTP) and their level of environmental concerns. While some analysis identified a premium for booking a standard room in a green hotel [15], others did not agree with this correlation [7]. The present study takes into account both points of view by introducing null, medium and high market appreciation of the green services. Ho Kang et al. [16] performed a survey investigating guests' WTP extra for green initiatives in hotels. The most frequent answers deriving from it were used as hypothesis for increasing the profit of the baseline scenario. The effect of comfort in guestrooms on guests' WTP in green hotels was questioned as well. It is recognized that service quality is the main determinant of consumer satisfaction, while "non essential attributes" such as commitment to sustainability deliver secondary benefits [17]. On the other hand, monitoring studies [18] proved that, given the same comfort level, occupants' of green buildings tend to complain less about IEQ than occupants of standard building. Rahman et al. [19] identified this behavior in green hotels as "willingness to sacrifice", which leads guests to accept lower service quality for higher rates. In the present case study all retrofit measures did not improve guests' comfort conditions, constantly within EN15251 Comfort Category III ($10\% < PPD \leq 15\%$). Following [19], the effect of low comfort level was not considered in the monetization of service price. The Istat data about the average yearly profit of a small size Italian hotel (Profit = 387 k€/y) was used as starting value, to which the null/increased WTP percentage was applied. The extra profit is accounted as negative value in the global cost-benefit formula.

Increased Market Value (MV). Market appreciation of energy efficient buildings has been confirmed by many studies. Most of the evidences are related to the effect of green certification on the real-estate market [20, 21]. The effect of retrofit actions on the market value of existing "unlabelled" buildings was studied by Popescu et al. [22]. Based on the quoted literature, three options of added value– low, medium and high - were considered and applied to the final value $V_{f,\tau}$ (j). The value increase is added to the original $V_{f,\tau}$ (j) in CB_G formula.

Table 3 recaps formulas and monetization options for each considered co-benefit.

Table 3. Co-benefits included in the global cost-benefit formula and their monetization options

Benefits			Eq.	Monetization options			
Cat.	Subcategory			Null (0)	Low (L)	Medium (M)	High (H)
Initial	Incentives (I)	B_I	B_I= I*C_I	I_0= 0%	-	I_M= 36%	I_H= 65%
Running	Productivity variation (P)	B_P	P = 0.1647524*T - 0.0058274*T^2 + 0.00000623T^3 - 0.4685328 B_P = P*Salary				
	Increased service price (sp)	B_{sp}	B_{sp} = sp*Profit	sp_0= 0%	-	sp_M= 5%	sp_H= 10%
Final value	Increased Market Value (MV)	$V_{MV,\tau}$ (j)	$V_{MV,\tau}$ (j) = $V_{f,\tau}$ (j) * MV	-	MV_L= 3%	MV_M= 9%	MV_H= 15%

c. Global cost-benefit formula and scenarios

The inclusion of the co-benefits listed above in the traditional global cost (C_G) formula resulted in a revised global cost-benefit (CB_G) formula, shown in Eq. (2).

$$CB_G(\tau) = (C_I - B_I) + \sum_j * \left\{ \sum_{i=1}^{\tau} \left[\!\left[\left(C_{a,i}(j) + B_P - B_{sp} \right) * R_d(i) \right]\!\right] - \left(V_{f,\tau}(j) + V_{MV} \right) \right\} \quad (2)$$

The CB_G formula was implemented for all the considered retrofit options.

In order to provide an overview of the potential of each co-benefits category in modifying the global cost for the proposed interventions, scenarios combining different benefits monetization options were created. However, not all scenarios were applied to all retrofit options. Since evidences of higher market values are related to the effect of energy certification, the hypothesis of medium and high increased MV were applied only to eco EEMs and packages of EEMs. A low market value increase was applied to standard retrofit options only. The same principle applies for the application of service price benefits. As increased guests' WTP depends on the green image of a hotel and green image is closely linked to green certification [7], increased service price was considered only in models with eco EEMs and packages of EEMs.

The implemented benefits scenarios are presented in Table 4.

Table 4. Monetization options included in different global-cost benefits analysis scenarios

Scenario	Monetization options	Applied to
00L	$I_0 + P + sp_0 + MV_L$	Standard EEMs and Packages of EEMs
M0L	$I_M + P + sp_0 + MV_L$	
H0L	$I_H + P + sp_0 + MV_L$	
00M	$I_0 + P + sp_0 + MV_M$	Eco EEMs and Packages of EEMs
00H	$I_0 + P + sp_0 + MV_M$	
0MM	$I_0 + P + sp_M + MV_M$	
0HH	$I_0 + P + sp_H + MV_H$	
MMM	$I_M + P + sp_M + MV_M$	
MHH	$I_M + P + sp_H + MV_H$	
HMM	$I_H + P + sp_M + MV_M$	
HHH	$I_H + P + sp_H + MV_H$	

4. Results and Discussion

a. Cost-optimal with global cost formula

In Figure 1 the primary energy uses of the RH and of all its variations implementing EEMs and Packages of EEMs are plotted versus their corresponding global costs.

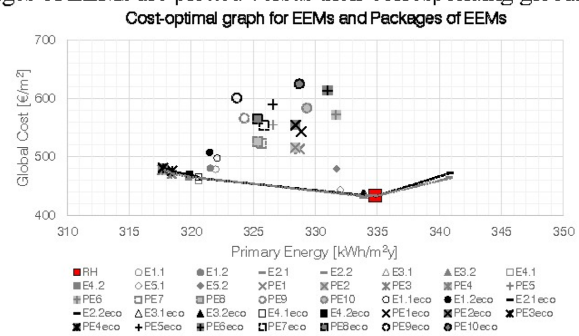

Figure 1. Global cost vs. primary energy for standard and eco EEMs and Packages of EEMs

Different kind of information can be inferred from the graph. The first deals with the difference in C_G between eco and standard EEMs and packages. Particularly, for interventions on the opaque envelope, extra 19 €/m² (e.g. $C_{G,E1.1eco} – C_{G,E1.1}$) to 41 €/m² (e.g. $C_{G,PE6eco}–C_{G,PE6}$) are accounted, meaning that, from a purely finance driven perspective, choosing eco-friendly retrofit options is not convenient.

Secondly, envelope retrofit options alone play a very limited role in reducing the total Primary Energy use of the building ($\Delta_{EP,max}$=23kWh/m²y). Almost no difference can be noticed between the two levels of energy performance of each EEM and Package and very small variations are spotted among different retrofit options. Indeed the reduced heating energy consumption obtained by increased U-values were counterbalanced, and in some cases surpassed, in the simulation results, by increasing cooling energy consumption. With these premises, it not surprising that the most energy efficient options (PE4/PE4eco, PE3/PE3eco, E4.2/E4.2eco, E4.1/E4.1eco) include windows substitution, able to reduce both dispersions and solar gains. The very low decrease in Primary Energy, translated into almost constant running energy costs (C_E) among all the options, entails the cost-optimal curve to have its minimum corresponding to the RH, where no investment costs can be accounted. Being here C_I the major influencing factor in the C_G formula, the more invasive the retrofit option is, the higher its C_G (e.g. = PE10/PE10eco). By taking into account the traditional global cost formula, the most convenient retrofit option is not to retrofit at all.

a. Cost-optimal with global cost-benefit formula

As mentioned, cost-benefit analysis scenarios applied to standard retrofit options were different from cost-benefit analysis scenarios applied to eco retrofit options. Figure 2 displays the outcomes of the revised global cost-benefit formula for the scenarios involving standard measures; Figure 3 refers to eco measures. For the sake of visual clarity, in Figure 3 only the cost-optimal curves are shown.

The first remarks involve the effect of productivity (P), variable included in all scenarios. As a function of indoor air temperature, B_P reduces the global cost only in case the indoor temperature of the retrofit option is most favorable for employees' productivity than indoor temperature of the RH. This is not the case of the present study, where the increased thermal performance of the envelope caused overheating. If workers' well being was considered as single extra variable in the global cost-benefit analysis, a slight increase in the CB_G of each option would have been noticed. From Figure 2, it can be inferred that the single effect of a modest market appreciation of the retrofitted RH in terms of its final value it is not enough to convince investors to go for energy efficiency. Indeed, there is almost no variation from EEMs C_G and their C_{BG} for scenario 00L. Slightly more noticeable variations within the same EEMs with different benefit scenarios can be found by varying the incentives benefits B_I. This variable is able to "flatten" the previously drawn cost-optimal curve so that the most energy efficient options become, in terms of CB_G, as convenient as keeping the RH in its initial conditions. However, from the investors point of view, considering all the practical inconveniences that a renovation process entails, not even high public incentives can play the key role in modifying the profitability of a project toward energy efficiency.

This graphs points out the aspect having the deepest impact on the economical convenience of a retrofit measure: the service price increase. Medium and high building market value increases alone do not modify, and in some cases slightly increase, the initial C_G, meaning that reduced productivity is able to neutralize market appreciation, if their effect is compared in economical terms. The role of B_I has the same trend as for standard measures. On the contrary, including service price benefits in the global cost-benefit formula, led to a reduction in global cost of 155€ for medium appreciation (+5% WTP), of 309€ for high appreciation (+10% WTP) for all the eco retrofit measures. While no retrofit strategy was convenient according to the C_G formula, the implementation of the CB_G draws a very different scenario for eco EEMs and packages. Taking into account medium or high increase in service price makes almost any retrofit option more profitable than the baseline scenario.

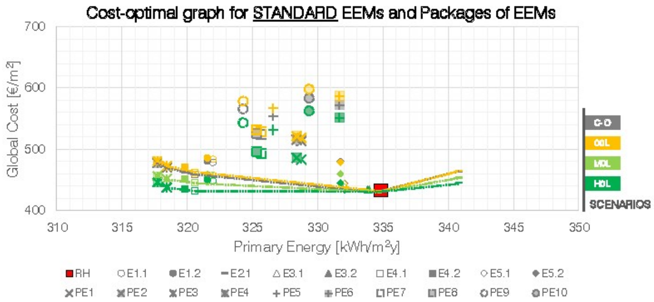

Figure 2. Global cost-benefit vs. primary energy for standard EEMs and Packages of EEMs

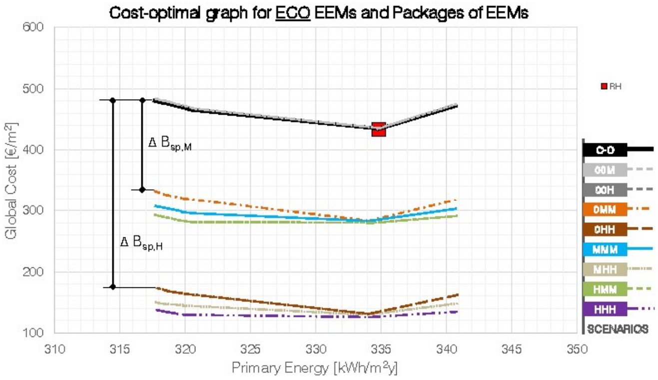

Figure 3. Global cost-benefit vs. primary energy for eco EEMs and Packages of EEMs

5. Conclusions

Aim of the present study was to address the problem of adding extra benefits to the traditional global-cost methodology, here intended as a decision making tool for investors at an early design stage. The inclusion of co-benefits in energy and economic evaluation is crucial for modifying investors' perception of the financial convenience of retrofit interventions.

Results showed that in a hotel building extra benefits related to increased service price (i.e. room rates) are the most effective factors for reducing the global cost of eco-friendly retrofit intervention. Despite the quantification of such market benefits is presented here via hypothesis based on literature review, their positive effect on green investment is a fact that the present research contributes to highlight. In addition, the study points out that employees' health and well-being have an important role, not just from an ethical point of view, but also in the financial performance of a building. Reduced productivity neutralized the impact of market appreciation for retrofitted and labelled buildings. Next steps of the research will take into account interventions to the building plants (such as mechanical ventilation) with the aim to investigate further the role of modified IAQ in affecting sick leave and productivity.

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Paper X

Of comfort and cost: Examining indoor comfort conditions and guests' valuations in Italian hotel rooms

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Original research article

Of comfort and cost: Examining indoor comfort conditions and guests' valuations in Italian hotel rooms

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ABSTRACT

Among co-benefits that energy efficiency interventions in buildings entail, occupants' improved comfort is one of the most acknowledged. In this study, a monetary valuation of improvements in comfort conditions in accommodation facilities was carried out. With an interdisciplinary approach to the problem, the evaluation was two-folded, aimed at monetizing co-benefits and extra costs of improved indoor environmental quality. Comfort co-benefits were estimated by employing the economic-based Contingent Valuation Method. In this framework, survey results allowed calculating respondents' Willingness to Pay for excellent comfort conditions in hotel rooms, quantified in a 14% increase of the room rate. The energy approach, based on dynamic simulations, allowed to quantify extra costs of improved thermal condition in a reference existing hotel. These findings suggest that guests' appreciation of comfort is higher than the investment costs required to provide them with comfortable conditions and highlight that energy efficiency measures are often necessary to reach the desired indoor comfort level.
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1. Introduction

Energy efficiency (EE) in buildings holds a leading role in European development strategies. Defined by finance and energy experts as an untapped resource for Europe's economic growth [1], it is a key area of actions in the transition to a low-carbon society envisaged by 2050 [2]. However, the current market up-take of EE projects in Europe is still disappointing, with an average renovation rate of the building stock around 1% [3]. The rising trend in the energy use in buildings, detected since 1990s, worsen the scenario [3]. In this context, tertiary sector is a major player [3] and, within this sector, hotels rank among the top-five energy use intensive categories [4,5]. Because of their high energy consumptions and the number of users they host, hotels represent an interesting building category to be considered in the low-carbon transition challenge.

To foster the scaling-up of EE projects in private and public sectors, many international reports [6–8] affirm that these investments generate a number of economic, social and competitive advantages, beyond the obvious energy and carbon savings. Recent studies proposed to include these less tangible advantages, defined in literature as co-benefits [9], in the valuation of EE projects [10–12]. This novel approach to the decision making process introduced new issues in the real estate appraisal discipline; while the identification of co-benefits gives rather universal results [13,14,6,8,15], their quantification is very case- and location- dependent [14]. Nonetheless, the monetary value of co-benefits needs to be estimated in order to include these aspects in the decision process for investments in energy efficiency.

Among co-benefits, increased indoor comfort appears as a key element in all the relevant literature on the topic, both from public and private perspectives [13,14,6–8,15]. This statement builds upon solid findings from on-field studies: many post-retrofit surveys revealed that increased comfort is the main source of occupants' satisfaction [16,17]. However, the translation of the unquestionable positive effects of increased indoor comfort in monetary terms is still poorly investigated. Indeed, valuing comfort in itself is one of the most difficult areas of economic evaluation of energy efficiency actions, because of the inner subjectivity of comfort perception. The scientific approach to the evaluation of

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comfort has evolved over years as an investigation of physiological, psychological and sociological factors, in particular in the field of thermal comfort. The well-known Fanger's theory [18], based on the evaluation of thermal neutrality between the occupant and his surroundings, was complemented by the adaptive comfort theory proposed by de Dear and Brager [19], who proved that occupants' level of adaptation and expectation is strongly related to outdoor climatic conditions as well. Recently, further theoretical developments suggested that occupants' motivation can play an even greater role in occupants' comfort preferences [20].

Placing an economic value on the improvement in comfort is a topic tackled by very few researchers so far. Clinch and Healy [21] valued post-retrofit increased comfort levels in dwellings by using the proportion of energy savings forgone as a proxy for the value that households placed on comfort improvements. For instance, if post-retrofit actual energy savings amounted to 60% of the potential energy savings predicted through calculations, the remaining 40% of forgone savings was assumed to equal households' implicit willingness to pay to increase thermal comfort in their dwellings. Simulation results revealed that comfort benefits amounted to 21% of the potential energy savings of the analysed building stock, after its hypothetical retrofit. Fang et al. [22] proposed a method that monetizes comfort levels based on pre and post-retrofit conditions. The Annualized Energy Related Cost (AERC) was calculated for several retrofit options of a reference residential building and plotted versus the comfort level, expressed in Fanger's indicators Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PPD). The difference in AERC between pre- and post-retrofit with the same comfort level (obtained thanks to a comfort-stat control in the simulation tool) represented comfort monetization, amounting to 10.6% increase in heating and cooling costs. The European Commission, in its guidelines for Cost-Benefit analysis for investment projects [23], suggests two possible cases for the evaluation of comfort benefits, based on a counterfactual scenario: (1) the pre and post- comfort levels are equal and the benefit is calculated as the energy savings obtained with the retrofit; (2) post-retrofit comfort level is higher than pre- and benefits are equal to the difference between the energy cost that pre-retrofit building would have had to reach the post-retrofit (higher) comfort level and the post-retrofit energy cost.

Common feature of these studies is that they monetize comfort as a function of the energy savings obtained by simulated energy efficiency measures in buildings. Moreover, the focus is on thermal comfort, mainly assessed through indoor temperature and Fanger's indicators, while psychological and sociological factors are not taken into account.

Monetization of co-benefits and competitive advantages are especially interesting for the hotel sector. In these buildings the large potential for operational costs reduction is coupled with the growing attention of costumers to ecological matters [24]. Particularly, valuing comfort is a stimulating task from hoteliers' perspective; Accommodation businesses build their success on the service quality offered, among which high indoor comfort levels are essential [25]. Because of this service-oriented nature, it is licit to infer that guests will be more sensitive to comfort as a factor influencing their willingness to pay.

Building on these premises, in the present paper a multidisciplinary approach is proposed to monetize comfort in hotels, taken from the economic and energy disciplines. From the economic side, the challenge to monetize comfort co-benefits was faced; being comfort a non-market good, the Contingent Valuation Method (CVM) was used to directly estimate the guests' preferences for it. While CVM has been employed in several studies for valuing outdoor environmental parameters such as acoustic annoyance [26] and air quality [27], no literature was found related to contingent valuation of comfort conditions in indoor environment, neither for single aspects influencing comfort (e.g. temperature, air quality), nor for its global evaluation. This study represents a first test of CVM for the estimation of a comfortable indoor environment. Particularly, the paper aims at quantifying the willingness to pay (WTP) for improved indoor environmental quality (IEQ) in hotel rooms through the preferences revealed by questionnaires given to potential guests. So far, the hotel sector has been object of many applications of the CVM aimed at evaluating guests' WTP for green practices [25,28], defined as an ancillary service. Findings of the present paper will explicit the link between comfort and willingness to pay in a direct way and enable a comparison between guests' preferences for essential (comfort) and non-essential (green initiatives) attributes offered by a hotel. From the standpoint of the energy evaluation, the extra costs of improved comfort conditions were investigated. The questionnaire-based results (economic approach) were compared to the rise in energy costs that a Reference existing Hotel may face in order to improve its thermal comfort level without undergoing any retrofit measure. Based on results of energy simulations, the increase in energy use and in the consequent energy costs for improved comfort conditions were assessed and the potential of energy efficiency measures to improve comfort while lowering the energy use was highlighted.

Framing this piece of research in the debate linking energy studies and social science allows to include its findings in broader avenues of research. These promising research paths have been unveiled only in recent years, in parallel with the growing need for an interdisciplinary approach to tackle world scale problems. Particularly, the study conducted by Sovacool [29] represents an important reference for energy research and social sciences research questions. Based on the quantitative content analysis of 15 years of research papers published by 3 major energy-related scientific journals, Sovacool identified 14 research paths with high potential for future development. Referring to Sovacool's findings, the present paper offers its contribution on one side to the application of human-centred research methods, on the other side to deepen the understanding of the how to boost private investments on R&D and innovation. Indeed, it couples personal opinions and experiences of comfort with economic and energy analysis, towards the understanding of the financial convenience of a comfortable indoor environment.

The paper is organized as follows: Section 2 presents the theoretical framework employed for the economic evaluation and the CVM technique; Section 3 describes the selected CVM survey instruments and the data collection process; Section 4 presents the framework for the statistical analysis used to evaluate the survey results, that are presented and discussed in Section 5. Section 6 compares the outcomes in terms WTP with the energy simulation results for a Reference Hotel, in which different comfort levels are set as the only variables of the model. Discussion of these findings and future projections are presented in Sections 7 and 8.

2. CVM theoretical background

In the economic discipline, Willingness to Pay (WTP) is used to directly valuate non-market goods. The direct valuation approach is used to measure the total economic value of a non-market good by asking for respondents' stated preferences (SP). Contingent Valuation Method (CVM) is among the most preferred technique because it can measure the total economic value of a good in a direct way. Conceived in 1947 [30], the CVM was first applied in the '60s [31] and since then it found wide applicability in the field of environmental economics [32,33]. For instance, many studies focused on outdoor environmental quality and on low carbon strategies, such as: noise reduction [34,26], air quality [27,35], CO_2 emission reduction [36], improvements in energy performance [37,38] and green initiatives in general [39].

Despite the wide and various fields of application, the CVM design steps are well established. A questionnaire has to be prepared and given to a random sample of respondents, who are asked to elicit preferences in monetary terms. More specifically, respondents are required to declare their maximum Willingness to Pay (WTP) or minimum Willingness to Accept (WTA) for changes in the quantity or quality of a good/service/policy. These changes may refer to a hypothetical or a real good or service, that needs to be realistically presented. The Contingent Valuation questionnaire involves three main stages: formulating the valuation problem, drafting additional questions and pre-testing of the questionnaire [40].

The valuation problem is the core of the investigation on WTP, and it builds on the construction of the valuation scenario and the elicitation of monetary values for the non-market good object of analysis. At this stage, the analyst needs to provide respondents with (1) a clear explanation of the changes proposed in the good/service/policy of interest, (2) a description of the market in which the good/service/policy take place and (3) details about the method of payment required. Moreover, the analyst has to decide the format of the elicitation question, that can potentially produce different estimates. The most popular elicitation methods are: open-ended, close-ended, iterative bidding game, payment card [40]. Open-ended elicitations ask respondent their maximum WTP. Close ended interrogations are based on the dichotomous choice approach and ask the respondent whether he would pay X to obtain the good or not. The iterative bidding game starts by querying individuals at some initial monetary value and keeps raising (or lowering) the value until the respondent declines (accepts) to pay. The final amount is interpreted as the respondent's WTP. With the payment card approach a number of possible WTP values are listed and the respondent is asked to pick the amount on the card that best represents his willingness to pay. The amount chosen by the respondent can be interpreted as the respondent's WTP.

Additional questions enable to draft interviewees' profiles and they constitute the starting point for building the estimations models. They are used to create the formula to predict the WTP. These questions are usually placed before and after the valuation problem. The opening part typically includes general (warm-up) questions aimed at introducing the topic of the questionnaire to the respondent and at inquiring his opinion on the subject. The last portion of the questionnaire is about respondents' socio demographic information, such as age, household income, marital status, educational attainment.

Pre-testing phase usually includes focus groups and pilot interviews, with the aim to test language, contents, potential emerging bias, willingness to pay upper and lower limits, etc. In order to obtain reliable results, the survey needs to be carefully designed and pre-test is a crucial stage.

Despite its success, several critics to CVM have been moved in literature. A major weakness identified is that the value attached to a non-market good is entirely hypothetical [41,42]. Respondents have no incentive to make a choice in an SP experiment in the same way as they would do in the real situation. For instance, a common phenomenon is the "warm-glow" effect, for which people enjoy saying that they would contribute to a good cause. Differences between real and hypothetical settings are referred to as "cheap talk" [43], which researchers try to limit this by adding a direct explanation of this problem to their survey document. Beside the cheap-talkers issue, the most quoted potential cause of bias is related to how the willingness to pay question is asked. Respondents' attitudes have deep influence on the reliability of responses and different elicitation methods can lead to different answers [44,45]. The main disadvantages of the different elicitation methods were extensively described by Pearce and Ozdemiroglu [44]. Typically, open ended questions can lead to high non-response rate and, in general, to less reliable responses; close ended queries generally provide over-estimated WTP with respect to the open ended form and provide less information to the analysists; in iterative bidding, respondents may be influenced by the starting values and succeeding bids proposed; payment card approach is exposed to biases relating to the range of the numbers used in the card and the location of the benchmarks.

Another important factor to be considered is the framing of the scenario presented to respondents [46,47]. As illustrated by Saayman et al. [47], if the scenario is too general (e.g. global warming), respondents may have too little knowledge of the hypothetical consequences of their answers. Moreover, a complex scenario could lead respondents to "non-action" answers. On the other hand, if the scenario is too specific, it may be perceived as not important.

Ex-ante and ex-post actions can limit the mentioned bias and legitimate the wide use of this stated preference method in economic investigations of non-market goods. Indeed, in current practice, CVM method represents a balance between the rigour of the method and time and budget issues [48].

3. Survey set-up and data collection

Based on the theoretical background presented in Section 2, in this study the Contingent Valuation Method was applied for the monetary valuation of excellent comfort conditions in hotel guestrooms.

An on-line questionnaire was the selected survey method. Web tools are a low cost option that guarantees short elapsed time for receiving answers, wide geographic spread and lack of bias due to the interviewer's presence and attitude. Moreover, even if authors are aware that web-respondents do not represent the full sample of population, the target population for this research – travellers – mostly do.

A series of focus group interviews was carried out in order to develop and check different sections of the questionnaire and a pre-test of the questionnaire was mailed to 20 respondents before the final version was send out. After revisions, the main survey was launched in June 2016, when the questionnaire was mailed to 900 persons through a Google Forms link, a web platform that allows creating and analysing surveys. 30 days were allocated for its completion. The geographic extension of the sample was the Italian territory and 20 was set as lower limit for the age of respondents.

The final version of the questionnaire consisted of four sections: I) consumers' attitude regarding accommodation, II) consumers' experience, III) payment scenario, IV) demographic and socio economic data. A copy of the questionnaire (English translation from the original in Italian) is enclosed in Appendix A.

In the first section, a few questions were performed to understand and individuate respondents' travel attitudes, frequency of and duration of trips, and type of preferred accommodation structure. A sub-section was specifically dedicated to investigate consumers' attention for any environmental policy undertaken by the hotels. Section II aimed at evaluating respondents' experiences in hotels related to comfort, referring to their acoustic, visual, thermal, and indoor air quality (IAQ) sensations in guestrooms and to any possible symptom of Sick Building Syndrome (SBS) (e.g. eye, nose or throat irritation, dry cough), due to indoor pollutants sources and low ventilation rates. Indeed, noise, light, temperature and ventilation rates are the main physical parameters influencing occupants' indoor comfort conditions, upon which standard CEN15251 [49] bases its classification of the indoor environment. In the questionnaire, for each comfort index (acoustic, thermal, visual and IAQ) a number of additional questions were asked about the

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Table 1
Description of the variables of the functions.

Variable	Description	Codification
Dependent Variable		
WTP	Willingness to pay for improved indoor conditions in hotel rooms	In monetary terms (Euro)
Independent Variables		
Socio-economic variables		
AGE	Respondent's age	In years since birth
GEN	Respondent's gender	GEN = 0 for female and GEN = 1 for male
INC	Respondent's income level	Amount of monthly income
EDU	Respondent's education level	Amount of school years
Travel attitudes		
TRIPS	Number of trips in the last year	In numbers of trips
ATIME	Average time spent in travel	Amount of days spent in each trip
PRICE/NIGHT	Average expenditure for each night in hotel	Average room rate per night (Euro)
MOTIVE	The motive for travelling	0 if it is a business travel, 1 if it is a leisure travel
Preferred accommodation		
AIRBNB	Respondent usually books in Airbnb or similar	0 if the respondent doesn't book; 1 if he usually does
B&B	Respondent usually books in Bed&Breakfasts	
RESIDENCE	Respondent usually books in residences	
HOSTEL	Respondent usually books in hostels	
1, 2STARS	Respondent usually books in 1/2-stars hotels	
3STARS	Respondent usually books in 3-stars hotels	
4STARS	Respondent usually books in 4-stars hotels	
5STARS	Respondent usually books in 5-stars hotels	
Environmental activities and attitudes		
ENVATTENTION	It investigates whether the respondent has ever paid attention to the environmental policy of a structure while choosing an accommodation	0 if the respondent never paid attention, if so the value is 1
ENVACCOMODATION	This variable explores the frequency of experiences in green accommodations	On a 5-points scale, 0 representing 'Never', 1 'Rarely', 2 'Sometimes', 3 'Often', and 4 'Very often'
ENVACTIVISM	A dichotomous variable that explains the personal involvement in pro-environmental activities	0 representing no interest and 1 full interest in environmental activity.
ENVATTITUDE	Factor loadings for considering the presence of an environmental policy as a key criterion in the choice of an accommodation	A scale between 0 and 1, 0 representing no interest and 1 full interest in selecting green accommodations
Experiences of discomfort in accommodation structure		
ACOUSTIC	Frequency of acoustic annoyance	The perception of the annoyance on a 5-points scale, 0 representing 'Never', 1 'Rarely', 2 'Sometimes', 3 'Often', and 4 'Very often'
VISUAL	Frequency of visual annoyance	
THERMAL	Frequency of thermal annoyance	
IAQ	Frequency of Indoor Air Quality annoyance	
SBS	Frequency of eye/nose/throat irritations in hotel rooms	

annoyance source and about remedies adopted to reduce annoyance. The latter type of questions aimed at assessing respondents' attitude towards uncomfortable indoor conditions.

The valuation problem was presented in Section III. After some background information aimed at pointing out the role of comfortable indoor environment in improving personal satisfaction and physical and psychological well-being, the issue of the extra operational costs for excellent comfort condition was presented. In hotels, an increase in room price was suggested as a solution to balance these extra-costs. Then, the core question was elicited as follows (translation from the original in Italian):

"*Suppose that you are going to spend one night in a double room in a hotel located in Turin Centre at a tariff of 80 €/night. Suppose that the comfort conditions of the guestroom are not satisfactory with reference to air quality, temperature, noise and light. Assume that the payment of an additional amount will help to improve and maintain excellent comfort levels in this room. How much is the maximum additional amount (€/night) that you would be willing to pay in order to enjoy excellent comfort conditions in your room?*"

The starting room rate was set equal to 80€/night based on web research on June 2016 tariffs for a double room in hotels located in Turin centre (source: www.booking.com). The framed scenario is very specific and close to respondents' personal experiences, both in terms of payment methods (increase in room rate) and proposed changes in the good (increase in comfort). As inferred by Carlsson and Johansson-Stenman [27], issues that relate to individuals are

Table 2
Main socio-economic data of respondents.

AGE		20–29 y	30–39 y	40–49 y	50–59 y	60–69 y
	Freq. (%)	99 (44.2)	75 (33.5)	24 (10.7)	18 (8.0)	8 (3.6)
GEN		Male		Female		
	Freq. (%)	101 (45.1)		123 (54.9)		
INC		0–1000 €	1–2000 €	2–3000 €		3–4000 €
	Freq. (%)	55 (23.8)	142 (61.5)	30 (13.0)		4 (1.7)
EDU		Secondary school	High school graduate	University degree		Postgraduate degree
	Freq. (%)	4 (1.8)	60 (26.8)	124 (55.4)		36 (16.1)

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less sensible to the "warm-glow" effect and allow respondents to behave as real consumers. Moreover, the easy understanding of the scenario minimizes the non-response risk and allows asking an open-ended question. Indeed, many advantages can be reaped by the analysists using the open-ended elicitation format: the question is simple and immediate, it does not affect respondents with anchoring values, it captures the maximum WTP for each respondent and it requires relatively straightforward statistical methods [44].

As coded, the demographic and socio-economic questions were placed in the last section, since these aspects could be more sensitive to some respondents (employment and incomes).

4. Analysis model

Contingent Valuation Method asks for specific statistical analysis in order to obtain meaningful findings. To this purpose, in the present paper descriptive statistics of responses were coupled with econometric estimations, both performed with the statistical analysis software SPSS (version 21) [50]. The questionnaire outcomes allowed the researchers to perform statistical analysis based on associations among variables. From the same data pool, different statistical techniques provided different informative contributions.

First, descriptive statistics characterized respondents in terms of main socio-economic features, travel and environmental attitude and perception of comfort in hotels. Then, the core of the statistical descriptive analysis aimed at obtaining the average and frequency distribution of respondents' WTP for increased comfort conditions in a hotel room were analysed.

As a supplementary analysis, aimed at providing insights on the links between WTP and respondents' characteristics, econometric estimations were carried out. Two models of multiple regression, linear and logistic, were developed in order to investigate the most suitable functional form to predict the willingness to pay for improvements in comfort conditions in hotel rooms. The multiple linear regression model, or multiple regression analysis, describes the relationship between a continuous dependent variable and several independent variables. The binomial logistic regression can be considered as a multiple linear regression, but for a dichotomous rather than a continuous dependent variable. This model is used to estimate the probability of a binary response based on one or independent variables [51].

The analysis included the main factor (WTP) and 25 independent variables, described in Table 1. We decided to include in the model the full range of factors that could have an influence on the respondents' WTP, in order to have a complete picture of the preferences of the individuals with reference to indoor conditions in hotel rooms. To each variable an alphanumeric code was assigned, coupled with codification values for its quantification in the econometric models.

The socio-economic variables are meant to capture objective differences in individual characteristics, while variables on travel attitudes explain the number of trips in the last year, the travel motive and the average expenditure per night for hotel room. The variables on environmental activity interest capture the subjective consumer propensities towards the environment issue. The last group of variables captures the consumers' experience of discomfort conditions (acoustic, visual, thermal and IAQ) in hotel rooms.

5. Survey results

In total, 273 questionnaires were returned (30% response rate), but, due to incomplete answers, only 224 questionnaires were considered valid (25% response rate). Based on literature [52], the sample size was considered large enough and the collected obser-

Table 3
Respondents' travel attitudes.

TRIPS		0–5 trips	6–10 trips	11–15 trips	16–20 trips	21–25 trips			
	Freq. (%)	171 (76.3)	42 (18.8)	6 (2.7)	3 (1.3)	2 (0.9)			
ATIME		1–2 days	3–5 days	1 week	2 weeks	>2 weeks			
	Freq. (%)	45 (20.1)	118 (52.7)	52 (23.2)	3 (1.3)	6 (2.7)			
PRICE/NIGHT		0–25 €	25–50 €	50–75 €	75–100 €	100–150 €			
	Freq. (%)	9 (4.0)	81 (36.2)	63 (28.1)	57 (25.4)	14 (6.3)			
MOTIVE		Work	Leisure						
	Freq. (%)	60 (26.8)	164 (73.2)						
Preferred accommodation		AIRBNB	B&B	RESIDENCE	HOSTEL	1–2 STARS	3 STARS	4 STARS	5 STARS
	Freq. (%)	70 (31.3)	101 (45.1)	27 (12.1)	18 (8.0)	19 (8.5)	119 (53.1)	60 (26.8)	5 (2.2)
Environmental activities and attitude			Yes						
	Freq. (%)	ENVATTENTION	65 (29.0)						
		ENVACCOMMODATION	129 (57.6)						
		ENVACTIVISM	72 (32.1)						
		ENVATTITUDE	86 (38.4)						

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Table 4
Respondents' experiences of discomfort in accommodation structures.

		ACOUSTIC Freq. (%)	VISUAL Freq. (%)	THERMAL Freq. (%)	IAQ Freq. (%)	SBS Freq. (%)
Perception	No	19 (8.5)	39 (17.4)	19 (8.5)	42 (18.8)	161 (71.9)
	Yes	205 (91.5)	185 (82.6)	205 (91.5)	182 (81.3)	63 (28.1)
If yes, restoring actions	No	172 (76.8)	64 (28.6)	25 (11.2)	47 (21.0)	
	Yes	52 (23.2)	160 (71.4)	199 (88.8)	177 (79.0)	

Table 5
Willingness to Pay for the sample.

	Mean [€]	St. dev. [–]	Median [€]	Mode [€]	Zero-bids [%]	Min. [€]	Max. [€]	N. [–]
WTP whole sample	11.47	8.104	10	20	17.9	0	40	224
Positive WTP	13.96	6.710	10	20	–	1	40	184

vations were the basis for the descriptive and the econometric analysis, presented below.

5.1. Descriptive analysis of the sample

The main socio-economic data of respondents are shown in Table 2. The frequency distribution reveals a large prevalence of young people (45% of the sample aged 20–29). Coherently, the lower monthly income segments are the most frequent (23.8% for 0–1000€/month and 61.5% for 1000–2000 €/month). The educational profile indicates that 71.4% of respondents have a degree.

Respondents' travel attitudes and tourism-related environmental awareness are summarized in Table 3. The majority of respondents took up to 5 trips (76.3%) in the last year, preferring short stays of 3–5 days (52.7%). The most common reason to travel was leisure (73.2%) and the most frequent average expenditure stood at 25–50€ per night (36.2%), with frequencies lowering with the increase in room rates. The preferred accommodation structures were 3-stars hotels (53.1%) and Bed&Breakfasts (45.1%). In terms of environmental attitude, one third of the respondent joined pro-environmental activities and 29% paid attention to green initiatives or certifications when booking an accommodation. However, 38.4% of the interviewees declared that the presence of green policies could represent a selection criterion when choosing a hotel to book. The mismatching between previous actions and future intentions may be explained with the warm-glow effect, for which respondents found gratifying to declare environmentally responsible choices. Finally, voluntary or not, 57.6% of respondents stayed in green structures.

The reported experiences of perceived comfort in guestrooms were very different within the sample in terms of frequency and parameters. Table 4 summarizes the general outcomes. The most perceived discomforts in hotel rooms dealt with acoustic and thermal annoyances, with 91.5% frequency each. Acoustic annoyance, mostly caused by transport infrastructures and disturbing noise, was solved by just 23.2% of guests, by wearing ear protections or moving to more silent areas. Instead, 88.8% of users improved their thermal comfort condition by contacting the hotel staff or by varying the thermostat temperature. 82.6% of the respondents would have preferred more natural light in their rooms. 71.4% of them reached a satisfactory visual condition by changing the blinds' position or switching the lights on. The least perceived uncomfortable index was IAQ. 81.3% of respondents noticed that in their room the air quality was very low. 79% of them solved the problem by opening the windows or by adjusting the system airflow. Finally, luckily, only 28.1% of guests experienced potential SBS symptoms (throat/eyes/nose irritations) during their stays.

Answers related to how guests restored their comfort are particularly important when potential energy consequences of discomfort are considered. Quoting the adaptive comfort principle [49,53], "If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort". Occupants' actions aimed at reaching comfortable comfort condition, such as the reported windows opening and thermostat set-points variation, can significantly increase the energy use of the hotel. Indeed, it is well recognized in literature that great variations in energy consumption of identical buildings may occur due to how occupants interact with system controls and the building envelope [54–56].

5.2. Aggregating and interpreting WTP

Objective of the paper was to monetize comfort in hotel guestrooms based on Willingness to Pay of potential guests. Interviewees were asked the additional amount per night they would pay for improving their comfort level in a guestroom and the obtained results are statistically described in Table 5.

About 18% of respondents (N = 40) stated a null additional WTP. Major cause for these zero-bids lied in the valuation scenario proposed in the questionnaire: the baseline room rate was 80 €/night, based on average prices for hotels in Turin centre. This starting price was perceived too high by most of the zero-bids respondents, who stated that, for such a tariff, their comfort expectations should have been satisfied by default. However, the mean WTP for increased comfort conditions was higher than 10€/night and the modal value was 20€/night when considering the positive WTP sample as well as the whole sample. In percentage terms, among the whole sample, an average 14% increase in the baseline room rate, quantified in 11.47€/night, was obtained as the marginal WTP *procapite*.

Frequency distributions and amounts of WTP of interviewees for improved IEQ were then matched with results of studies investigating guests' WTP for staying in green hotels, with the aim to compare the value attributed by potential guests to comfortable guestrooms with respect to the value attributed to eco-friendly practices. Particularly, objects of comparison were results from the WTP investigations performed by Manaktola and Jauhari [25] and Kang et al. [39], where the same investigation methodology of the present paper was applied. In [25] 66 respondents from the National Capital Region of India were asked their WTP for staying in hotels that follow environmental practices. Kang et al. [39] proposed to their 452 U.S.-based respondents two WTP related questions: the first question asking whether or not they would pay extra for staying in a green hotel, the second inquiring the percentage extra of the hotel bill the person would be willing to pay to support the hotel's environmental efforts. WTP responses are summarized in Table 6.

The different composition of the interviewees' sample does not allow a direct comparison among results. Even results of the valuation investigations on the same attribute – green initiative – shows almost contradictory findings ([25] versus [39]). Kang [39] identified the degree of environmental concerns of respondents and the

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Table 6
Comparison of WTP results for comfort and green initiatives.

Investigated attribute	Source		WTP (extra% of the bill) [%]													
			0	1	2	3	4	5	6	7	8	9	10	11–15	16–20	>20
Comfort	Present study	Relative frequency of answers [%]	17.9	0.4	–	1.8	0.4	–	9.4	–	–	–	1.8	28.6	6.7	33.0
Green initiatives	[25]		85.0	9.0			6.0			–						
	[39]		33.6	37.4					23.5					3.7	0.9	0.9

time periods of the interviews as possible major causes of this discrepancy in findings. Indeed, social and contextual factors have a strong influence on guests' preferences. In this view, Italian respondents widely differ from both the India and U.S. based respondents' pools. A punctual analysis in terms of percentage differences would be misleading and inappropriate.

Nonetheless, some interesting general conclusion can be drawn from the presented figures: when dealing with comfort related WTP, less zero-bids were detected and a marginal WTP higher than 11% was much more frequent, stated by 68.3% of the sample. These findings confirm the different relevance between core and ancillary functions of accommodation structures. Providing hotel guests with tangible comfort is an essential attribute, to which guests are more sensitive. On the contrary, green initiatives offer to guests intangible benefits, related to the purchase of moral satisfaction [57], whose perceived economic value is lower.

5.3. Estimation results

The econometric estimation models developed in this research allowed understanding the associations among respondents' characteristics and their WTP. These information supplement and enrich the understanding of the main investigation problem of this research, the WTP valuation.

Various statistical techniques can be used to perform the analysis of the collected data. The choice should take into account a number of factors, such as the objective of the analysis (e.g. investigating the influence of one, two or several variables in the prediction) and the nature of the data (e.g. quantitative/qualitative).

Since, as mentioned above, the objective of the estimation models was to verify the presence and to quantify the influence respondents' features on WTP, a multivariate analysis was preferred. Particularly, the study performed a multiple regression analysis (linear) and a binomial logistic one. The two WTP equations were obtained using SPSS 21 [50].

First, the analysis included the dependent variable (WTP) and all independent variables (socio-economic, travel attitude, environment activities and attitudes, and perception of discomfort conditions). The WTP was translated into a dummy variable, in order to include it in both analyses, keeping in mind that, unlike multiple linear regression, the binomial logistic one can only be used to predict a dichotomous dependent variable. We considered only two values that we coded as zero or one, where '0' represented the unavailability, while '1' any additional price for better indoor comfort conditions by respondents. Since nominal variables about discomfort conditions and environmental accommodation had more than two choices, they were translated in dummy variables; to 'Never' option the value of '0' was assigned, while 'Rarely', 'Sometimes', 'Often', and 'Very often' choices were allotted the value '1'.

Then, the estimation models were refined by including in their formulas only relevant variables, which were selected according to their significance in the full model. In order to test the significance of a variable, the p-value must be lower than the significance level defined a priori by the analysts. Typical significance level thresholds, selected for this analysis, are 0.1, 0.05 and 0.01. Therefore, only the variables showing p-values lower than 0.1 were included in the refined estimation models [58].

The coefficients of the estimation formulas represent the dependence of the dependent variable (WTP) on its related independent variable, net of the other independent variables in the equation.

The goodness-of-fit of the estimation models represent how much variability the model is able to explain, based on the initial data. This value, expressed in percentage terms, is measured by the R^2 coefficient. Moreover, the F-test allows identifying the model

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that best fits the population from which data where sampled. The results and predictive performances of the regression models are shown in Table 7.

5.3.1. Multiple linear regression

One way ANOVA in linear regression was performed to test the statistically sufficiency of the model. Since the *F*-value is equal to 1.971 and *p*-value to 0.006, the model fit is statistically sufficient. The R-square (R^2) in multiple regression analysis is 0.098. To test the variables significance in the full model, the *p*-value of each variable was taken into account. The resulted significant variables are GEN (gender, *p*-value = 0.019), TRIP (trips number, *p*-value = 0.050), B&B (B&B accommodation frequency, *p*-value = 0.028), ENVACTIVISM (personal activism in environmental issue, *p*-value = 0.018), ACOUSTIC (acoustic discomfort annoyance, *p*-value = 0.009), IAQ (indoor air quality discomfort annoyance, *p*-value = 0.012), THERMAL (thermal discomfort annoyance, *p*-value = 0.046). The reduced multiple linear regression included in the analysis only the signifi-

Table 7
Summary of multiple linear and logistic regression.

		Multiple Linear Regression		Binomial Logistic Regression	
Full model					
	F-value	1.971		–	
	p-value	0.006*		0.005*	
	R^2 | Nagelkerke R^2	0.098		0.310	
	Variables	Coefficient	*p*-value	Coefficient	*p*-value
Socio-economic variables					
AGE		−0.073	0.395	−0.034	0.208
GEN		−0.164	0.019**	1.038	0.023**
INC		−0.007	0.932	0.000	0.741
EDU		0.001	0.987	−0.017	0.822
Travel attitude					
TRIPS		−0.154	0.050**	−0.114	0.044**
ATIME		−0.029	0.685	−0.011	0.843
PRICE/NIGHT		0.081	0.366	0.011	0.326
MOTIVE		0.043	0.574	−0.323	0.572
Preferred accommodation					
AIRBNB		−0.021	0.772	0.089	0.859
B&B		−0.159	0.028**	1.109	0.023**
RESIDENCE		0.036	0.600	−0.146	0.837
HOSTEL		−0.006	0.934	0.017	0.927
1–2 STARS		−0.001	0.989	−0.351	0.668
3 STARS		−0.001	0.984	−0.055	0.902
4 STARS		0.062	0.450	−0.765	0.260
5 STARS		0.066	0.333	−19.147	0.999
Environmental activities and attitude					
ENVATTENTION		0.017	0.821	−0.131	0.817
ENVACCOMODATION		0.070	0.323	−0.374	0.388
ENVATTITUDE		0.035	0.634	−0.381	0.453
ENVACTIVISM		0.176	0.018**	−1.398	0.013**
Experiences of discomfort					
ACOUSTIC		0.184	0.009*	−1.687	0.015**
IAQ		0.177	0.012**	−1.369	0.010**
THERMAL		−0.143	0.046**	1.712	0.067***
VISUAL		0.043	0.550	−0.298	0.586
SBS		−0.052	0.461	0.552	0.273
F-value			1.971		–
R^2 | Nagelkerke R^2			0.098		0.310
Reduced model					
	F-value	5.625		–	
	p-value	0.000*		0.000*	
	R^2 | Nagelkerke R^2	0.127		0.213	
Socio-economic variables					
GEN		−0.171	0.009*	1.109	0.006*
Travel attitude					
TRIP		−0.155	0.023**	−0.106	0.020**
PRICE/NIGHT		0.139	0.032**	0.014	0.045**
Environmental activities and attitude					
ENVACTIVISM		0.144	0.032**	−0.891	0.063***
Experiences of discomfort					
ACOUSTIC		0.170	0.009*	−1.176	0.036**
IAQ		0.172	0.009*	−0.952	0.032**
THERMAL		−0.125	0.063***	–	–
F-value			5.625		–
R^2 | Nagelkerke R^2			0.127		0.213

* Statistically Significant at 1%.
** Statistically Significant at 5%.
*** Statistically Significant at 10%.

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Table 8
EN15251 Indoor Environmental Quality categories for thermal comfort requirements for spaces with sedentary activities.

Category	Applicability	PMV	Operative temperature set-point for heating [°C]	Operative temperature set-point for cooling [°C]
I	High level of expectation	−0.2 < PMV < + 0.2	21	25.5
II	Normal level of expectation	−0.5 < PMV < + 0.5	20	26
III	Moderate level of expectation	−0.7 < PMV < + 0.7	18	27
IV	Values outside the above categories	PMV < −0.7 or PMV > + 0.7	–	–

cant variables: GEN, TRIP, PRICE/NIGHT, ENVACTIVISM, ACOUSTIC, IAQ, THERMAL. Results changed in significance terms, reaching better performances. The model fit of the reduced model was better than the full model; the *F*-value was equal to 5.625, the R^2 to 0.127 and *p*-value less than 0.000.

5.3.2. Binomial logistic regression

The model fit was tested through the Nagelkerke R^2, that is a pseudo R-square, and the *p*-value. Indeed, logistic regression misses the equivalent R-square, used in linear regressions. The model fit is statistically sufficient with Nagelkerke R^2 equal to 0.310 and *p*-value to 0.005. The significant variables in the logistic full model are the same of the linear regression one, as shown in Table 7. In the reduced model, the significant variables were: GEN, TRIP, PRICE/NIGHT, ENVACTIVISM, ACOUSTIC, IAQ. In this case, the value of pseudo R^2 was lower than that of the full model (Nagelkerke $R^2 = 0.213$), but significance was higher (*p*-value < 0.000).

Interestingly, the sign of the coefficients referring to dichotomous variables is reversed in the two models. In the linear regression model being male, the involvement environmental activities and previous experiences of acoustic and air quality discomfort contribute in raising the WTP. On the opposite, these features decrease the predicted WTP in the logistic regression model. Given two models that predict contradictory outcomes, the one yielding the better empirical interpretation of data must be chosen. By comparing the information emerging from the two regression analyses – R^2 (linear regression) and Nagelkerke R^2 (logistic regression) – the better-fit model is the logistic one where the independent variables predict more reliably the value of the dependent variable (WTP).

Despite the opposite sign, according to both regression analyses the most significant independent variable is gender (GEN), in line with findings from previous studies [59,60]. Moreover, in both models the WTP seems to be strongly correlated (positively in linear model, negatively in logistic model) with ACOUSTIC and IAQ discomfort data.

6. Effect on energy consumption

A simulation-based analysis was performed in order to investigate the energy-related consequences of improving indoor environmental quality in a hotel building. Specifically, object of the analysis was thermal comfort; according to the survey results, indoor thermal conditions were the most perceived causes of annoyance (91.5% of respondents). Moreover, in the hypothesis of improving comfort conditions in an existing hotel, indoor temperature is the easiest parameter to modify. Indeed, with small variations in the HVAC (Heating, Ventilation and Air Conditioning) system settings, indoor temperature (and ventilation, if mechanical) can be adjusted to more comfortable levels. On the contrary, improving natural lighting and acoustic insulation would entail costly and invasive physical interventions on the building envelope.

In this section of the study, thermal comfort was evaluated through Fanger's PMV index. As widely known, according to Fanger's theory [18], six main factors affect thermal comfort: metabolic rate, clothing level, air temperature, radiant temperature, air speed and humidity. PMV expresses the average response of people to these features through a 7 points thermal sensation scale ranging from −3 to +3, where 0 is the neutral feeling, −3 is cold and +3 is hot. Categories of thermal environmental quality based on PMV index were introduced in the European standard EN15251 [49]. Based on the comfort category to be reached, the standard suggests set-point temperatures to be set in buildings. Classification of comfort categories based on PMV and operative temperatures are shown in Table 8.

To simulate the effects of thermal comfort upgrades, a Reference Hotel (RH), described in Ref. [61], was modeled in the dynamic building energy simulation software EnergyPlus (version 8.3) [62]. According to Annex III of the EPBD recast [63], Reference Buildings are "buildings characterized by and representative of their functionality and geographic location, including indoor and outdoor climate conditions". They aim to represent the typical and average building stock in terms of climatic conditions and functionality (e.g. residential buildings, schools, etc.). In this view, the RH model

Table 9
RH main features for form, envelope, system and operation.

Class of parameters	Parameter	Unit	Value
Form	Gross area	m^2	2117
	Gross conditioned area	m^2	1700
	Number of floors	–	5 (4 + basement)
	Orientation	–	S-N
	Aspect ratio (S/V)	–	0.28
	Window/Wall ratio	–	0.17
	Number of guestrooms	–	49
	Number of beds	–	95
Envelope	Average opaque envelope U-value	W/m^2K	1.17
	Average glazed envelope U-value	W/m^2K	5.46
System	Ventilation	–	Natural
	Heating system	–	Centralized, with radiators
	Heating energy source	–	Natural gas
	Cooling system	–	Centralized, with split
Operation	Schedules	–	From UNI 10339:2009, EN15251

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Table 10
Energy performance and energy cost of the RH models with different thermostat settings.

			II CC Op. Temp.	I CC PMV guestrooms	Variation	
					net	%
Energy Performance	Primary Energy per Conditioned Building Area	kWh/m^2y	322.11	354.63	32.52	10%
	Electricity per Conditioned Building Area	kWh/m^2y	103.07	108.84	5.77	6%
	Natural Gas per Conditioned Building Area	kWh/m^2y	69.23	85.26	16.03	23%
Energy Costs	Total Energy Costs	€/y	49,718.53	54,156.54	4,438.01	9%
Specific Energy Costs	Electricity Costs per Conditioned Building Area	€/m^2y	23.71	25.03	1.33	6%
	Natural Gas Costs per Conditioned Building Area	€/m^2y	5.54	6.82	1.28	23%
	Total Energy Costs per Conditioned Building Area	€/m^2y	29.24	31.85	2.61	9%
	Total Energy Costs per Room per Day	€/(room*day)	2.78	3.03	0.25	
	Total Energy Costs per night spent	€/(guest*night)	7.26	7.90	0.65	

was built to portray a major share of the Italy's hotel buildings stock, as the baseline model for meaningful and widely applicable energy and economic evaluations. A few modeling methods are available in literature to build these archetypes. Among them, the approach proposed by Corgnati et al. [64] was applied to create the RH model. Form, envelope, system and operation parameters were collected following the example building and real building data collection approaches. The former is based on experts' assumptions and studies and it is chiefly used when statistical data are not available; the latter exploits data of existing building showing the most statistically relevant features of a certain category.

Based on its statistical relevance at national level, the RH depicts a specific sub-category of hotel buildings: it represents a 3-star, medium-size, urban hotel, open all year, built between 1921 and 1945 and located on the Italian Middle Climatic zone (Heating Degree Days = 2100–3000). The main model features, presented in Ref. [61], are recalled in Table 9.

As a representative city of the Middle Climatic Zone, Turin was selected to locate the RH Energy Plus model, using as weather data the Italian Climatic data collection Gianni De Giorgio (IGDG) (HDD = 2842, Cooling Degree Days = 287). This choice also allows a coherent comparison between the WTP findings (the valuation problem was elicited referring to a hotel located in Turin Centre) and the energy simulations results.

The thermostat control logic in guestrooms was varied following the scenarios drafted in the WTP questionnaire (i.e. to enhance comfort conditions of a hotel room), by running two different simulation scenarios. The baseline scenario, with normal thermal comfort conditions, was simulated by setting operative temperature set-points for heating and cooling coherent with EN15251 dispositions [49] for II Comfort Category (CC). The upgraded scenario, with "*excellent comfort conditions*", was modeled by setting in guestrooms a comfort control mechanism that impose the operative thermostat set-point to adapt in order to meet a specified PMV value, that was set to 0 (thermal neutrality) in compliance with Comfort Category I.

Energy performances of the two scenarios and their related energy costs are shown in Table 10. In order to compare the simulation based results with the outcomes of the WTP questionnaire, daily energy costs per guestroom are presented. Moreover, the energy cost per night spent is presented because of the relevance that night spent indicator has in the hotel sector, as a meter of business success. For the purpose of costs calculation, unitary costs of energy were derived as mean values from the analysis of energy bills of an existing 3-stars hotel located in Turin (natural gas = 0.08 €/kWh; electricity = 0.23 €/kWh) and the average number of nights spent in 3-stars hotels was derived from the national statistic institute (Istat). Coming to results, improving comfort conditions in guestrooms led to a 10% increase in primary energy consumption and to a 9% increase in the annual energy costs of the hotel. In specific terms, this extra energy use would cost to the hotelier 0.25 €/(room*day), obtained by dividing the daily extra energy costs (4438/365 = 12.16 €/day) by the number of guestrooms of the RH (49). Recalling results shown in Table 5, it is evident that guests' valuation of satisfying comfort conditions, monetized in a mean marginal WTP of 11.47 €/(room*night), goes much beyond the actual energy costs of improved IEQ. On the other hand, it must be noted that the obtained WTP was related to the improvements of all the main aspects related to indoor comfort (thermal, IAQ, visual, acoustic) [49], while the estimated extra costs dealt with better thermal conditions only.

Beside costs, the simulated thermal comfort conditions were investigated in order to verify the coherence between imposed conditions (i.e. thermostat settings) and perceived comfort (i.e. PMV values during the yearly simulation). The monthly PMV values of a thermal zone representing the RH typical guestrooms floor were analysed for the two simulated scenarios. Results are shown in Fig. 1. In the graph, areas in different shades of grey represent the ranges of PMV values for comfort category summarized in Table 8; the darker the grey of the plot, the worst comfort category. White dots (series "II CC Op. Temp.") represent the average monthly PMV value for the selected thermal zone when imposing thermostat settings based on the requirements for II Comfort Category in terms of operative temperature, as modeled in the RH baseline model. Black dots (series "I CC PMV guestrooms") report the monthly PMV values for the same thermal zone, when imposing comfort based thermostat settings (i.e. to adjust operative temperature in order to obtain PMV = 0) The closer the dots to the 0 PMV value, the higher the indoor thermal comfort.

As expected, the baseline model ("II CC Op. Temp."), where thermostat is set according to II Comfort Category requirements, has low thermal comfort performances. The comfort level of the upgraded model ("I CC PMV guestrooms"), on the contrary, lies most of the time in Comfort Category I. However, it is worth noting that in no scenario the monthly PMV level always falls within the imposed comfort category limits. It may be inferred that the building system is not able to deliver the required performance because of the very poor envelope thermal performances. Indeed, the very high thermal transmittance of the envelope components deeply affects their surface temperature and, consequently, the mean radiant temperature of the thermal zone. Provided that operative temperature is calculated as the weighted average of the mean radiant and ambient air temperatures, the influence of the thermal properties of the envelope on the perceived comfort conditions becomes evident.

These findings suggest envelope-related Energy Efficiency Measures (EEMs) as necessary to guarantee excellent thermal comfort conditions in the RH. Moreover, EEMs has the potential to reduce the energy costs and, consequently, to lower the extra energy cost of improving thermal comfort. This scenario could result in a win–win situation for a hotel business, where at the same time operational costs lessens and guests' satisfaction increases. Although these interventions may require capital intensive investments, they have relevant additional positive effects on the business success; they

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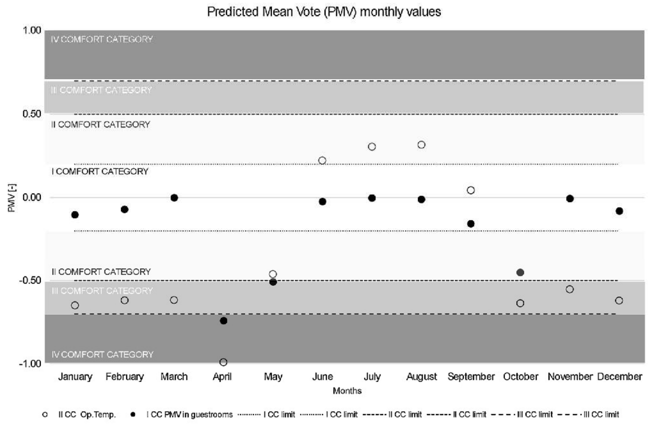

Fig. 1. Average monthly values of PMV for a typical guestrooms thermal zone of the RH.

can improve the visual and acoustic indoor environmental performances and renew the overall image of the hotel, in line with new green trends and CO_2 requirements.

7. Discussion

In the present study the effects of improved indoor comfort conditions in hotel rooms were investigated from a double perspective. On one side, an economic valuation technique, the Contingent Valuation Method, was employed to discover the Willingness to Pay of potential guests for staying in guestrooms with excellent comfort conditions. On the other side, energy simulations were run to detect co-energy costs of improving comfort conditions in the guestrooms of a Reference Hotel. The aim was to address the problem of the monetization of comfort as a co-benefit to be included in the evaluation of the economic convenience of retrofit interventions, from an investor's standpoint, identified as a hotelier in this paper. A positive balance between potential co-benefits and extra costs of guests' comfort was the envisaged outcome.

The few previous studies related to the monetization of comfort based their valuation on the post-retrofit energy savings and/or improved comfort obtained by hypothetical EEMs [21,22]. In this paper, a multidisciplinary approach crossing the economic and energy discipline was preferred, in order to seize behavioural aspects and comfort preferences. The CVM survey highlighted that, on average, the potential guests, represented by the sample of the survey respondents, were willing to pay a 14% higher room rate in order to experience excellent comfort conditions in their hotel rooms. This marginal WTP is considerably higher than guests' WTP for staying in green hotels found in literature [25,39]. It may be inferred that market appreciation is higher for comfortable hotels, rather than for eco-friendly ones and that, consequently, comfort indicators should be included in the evaluation of investment projects. It is also worth noting that the majority of respondents that experienced visual, thermal and IAQ discomfort modified their indoor conditions by interacting with the rooms' controls (e.g. opening windows, modifying the set-point, switching on the lights). Being users' interaction with controls one of the main causes of the energy performance gap, comfort indicators also have the potential to guarantee more reliable forecast of energy consumption, due to lower interactions users-controls. Additionally, the econometric analysis of answers highlighted that, for the interviewed sample, a logarithmic function of multiple regression describes the relation between WTP and the investigated dependent variables better than its linear counterpart. However, the two tested functional forms shared the same significant variables (p-value <0.1): gender, number of trips, average expenditure for accommodation, pro-environmental activities and experiences of acoustic and Indoor Air Quality discomfort. Particularly, being male and travelling a lot decreased the WTP, while the other variables have a proportional relation with WPT. However, when drawing these conclusions, the boundaries of the analysis have to be recalled. Indeed, as a trial test in this interdisciplinary field, only Italian respondents' answers were analysed to derive Willingness to Pay information. For instance, the influence of hotel guests' homeland in energy use patterns and hotels' revenues in Taiwan was object of the analysis carried out by Wang and Huang [65]. Through multiple regression models, the authors found out that the energy consumption and profits varied with hotels' regional guest ratios.

On the same line, variations in terms of socioeconomic composition or travel attitudes of respondents could have led to different outcomes of the econometric analysis. Even the same respondents could have given different answers, if interviewed at a different time. Indeed, valuing comfort is a very delicate and subjective task. As occupants' comfort perception and energy related behaviours are the products of physical, contextual, physiological, psychological and social drivers [66], any difference in the survey methods or participants (e.g. proposing the questionnaire in a different country or at a different time of the year) could have given different findings. In this framework, the insights offered by the present research are just the starting point for broader investigations, able to seize a more comprehensive range of drivers influencing guests' preferences.

Beside the context dependent findings, the scale of applicability of the proposed method is wide. It suggests a new approach to the quantification of comfort as a co-benefit, by applying economic valuation techniques to a problem that was, so far, tackled with a pure engineering approach, i.e. through energy simulations. In the parallel investigation, the extra costs of improving indoor ther-

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mal comfort conditions in an existing hotel were evaluated through energy dynamic simulations of a Reference existing Hotel. Reaching the highest comfort category (as defined in EN15251) in guestrooms led to a 9% increase in the annual energy costs of the hotel, or, in specific terms, to an extra-cost of 0.25€/(room*day). Given that the average marginal WTP of respondents was quantified in 11.47€/(room*night), the desired positive balance between co-benefits and extra costs is obtained. However, the valued co-benefit took into account all parameters contributing to a comfortable indoor environment, while extra costs, at this stage, considered thermal satisfaction only. In the RH, increasing ventilation rates, reducing noise annoyance, and increasing natural light, would entail the implementation to system and envelope-related EEMs, such as the installation of a mechanical ventilation system and windows substitution. In this scenario, the extra costs related to comfort increase would raise, including EEMs investment costs. Moreover, from a simulation-based verification of comfort conditions in the upgraded model of RH, it emerged that, in hotels with very poor envelope thermal performances EEMs may be necessary to provide guests with constantly optimal thermal comfort conditions as well. Indeed, existing plants of the RH proved not to be able to fully satisfy the new loads requirements. These results suggest investments in energy efficiency as the key to exploit the potential of comfort-related co-benefits in existing accommodation structures.

In the analysis of these simulation-based results, the geographical concern emerges again. A different location of the simulation models would generate different energy costs and indoor comfort conditions, that may or may not lead to increased revenues from the comparison between co-benefits and extra costs. Potential simulation models and locations are endless. However, once again, role of the present paper is not to provide a univocal answer, but rather to suggest the combination of an engineering approach (i.e. energy simulations) with econometric investigations (i.e. WTP) as a way to spot the gap between the calculated and perceived value of comfort.

8. Conclusions

The paucity of studies investigating the monetary value of improved indoor comfort conditions led the authors to consider an alternative approach to the problem, based on an interdisciplinary approach that consider a combined energy-economic perspective. The present study represents the first test of the Contingent Valuation Method to the valuation of comfort, with a specific focus on hotel rooms. From the survey, it emerged that on average respondents were willing to pay an extra 14% of the room rate, around 11.5 €/(room*night), for enjoying comfortable indoor condition. Moreover, a regression model allowed to define the significant respondents' characteristics influencing WTP. Further development of this investigation should pursue an enlargement of the respondents' pool, in order to verify the obtained results and refine the regression models. Moreover, the CVM could be coupled with another economic-based method to evaluate non-market goods, the Choice Experiment [67,68]. This technique assumes that goods or services can be described in terms of their attributes and asks respondents to choose between alternatives. With this approach, respondents' preferences for each aspect of indoor comfort (visual, acoustic, thermal, IAQ) could be estimated.

The parallel simulation-based investigation suggested that in a Reference Hotel the operational extra costs for improving indoor comfort condition are lower than the WTP stated by respondents. However, the obtained results also highlighted that Energy Efficiency Measures were needed in order to fully satisfy guests' comfort expectations. Next steps of the research should focus on the quantification of the extra costs of envelope and system upgrades, in order to have a more coherent and comprehensive comparison among extra costs and co-benefits of improved Indoor Environmental Quality.

These extra costs could be considered, for instance, as the investment cost to improve opaque and transparent envelope of buildings; insulating the opaque envelope would improve the efficiency of the building, replacing the old windows would ensure a higher sound insulation. The estimation of these investment costs would allow calculating the opportunity costs for better thermal condition and great acoustic comfort respectively.

From both the economic and energy investigative standpoints, varying the geographical coverage would give additional value to the research in its future developments. On one side, it would allow to investigate the influence that respondents' provenience have on their comfort and travel preferences. On the other side it would open research questions linked to the economic convenience of maintaining comfortable indoor conditions in different climate conditions. In this view, both the econometric and engineering approaches to the valuation problem allow replicability to different geographic contexts, as they chiefly require varying the respondents pool and the simulation model features and location respectively.

Beside the envisioned operative progresses in the energy and economic aspects of this research, a further conceptual leap will be needed in future developments, in order to include adaptive and motivational drivers in the perceived comfort conditions. In the present study comfort is still evaluated in terms of sensitivity to physical parameters (e.g. light, noise, temperature), while a growing branch of studies state the need to achieve a deeper understanding of the motivation structure towards the concept of "forgiveness" and comfort-adaptive (and energy-saving) behaviours [20,69]. Results presented above suggest that in a refurbished hotel the indoor environmental parameters can be improved to meet the very high guests' comfort expectations. By embracing the motivational approach, guests of an energy efficient hotel may be supposed to prefer energy saving indoor environment settings (e.g. they may found the II Comfort Category satisfactory). Evidences from field monitoring support this new statement; studies [70] proved that, given the same comfort level, occupants of green buildings tend to complain less about IEQ than occupants of standard building. This new approach to comfort open the doors to further investigations in an important field of the energy research and social science debate, Communication and persuasion [29].

Generalizing the issue faced in the present paper, monetization of co-benefits deriving from energy efficiency interventions in buildings is a complex task that goes beyond the financial appraisal of positive and negative cash-flows. Non-market goods, such as comfort or increased energy security, ask for an interdisciplinary approach to the problem, where the economic approach is interwoven with energy analysis and behavioural studies.

Appendix A. Questionnaire:

Questionnaire:

[The purpose of this English translation of the original Italian questionnaire is to give an overall presentation of the questions asked. The English version is not produced with the purpose of surveying native English speaking respondents.]

Valuing comfort in hotel rooms

The present questionnaire was designed for academic purpose and it aims at estimating the economic value of benefits related to the stay in hotel rooms with excellent comfort conditions. Among

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others, better sleeping quality a reduced level of stress are well evident benefits.

The following questions explore potential guests' attention and sensitivity toward the indoor environmental quality of accommodation structures. Also, the questionnaire assesses the potential willingness to paying of guests for enjoying comfort-related benefits.

TRAVEL HABITS

1. Approximately, how many trips did you make in the last year? _________
2. The reason of your trips is mainly:
   - ☐ Work
   - ☐ Leisure
3. On average, how long do your trips last? *(single choice)*
   - ☐ 1-2 days
   - ☐ 3-5 days
   - ☐ 1 week
   - ☐ 2 weeks
   - ☐ More than 2 weeks
4. What kind of accommodation do you usually prefer? ***(multiple choice allowed)***
   - ☐ Airbnb
   - ☐ Bed&Breakfast
   - ☐ Residence
   - ☐ Hostel
   - ☐ 1-2 stars hotel
   - ☐ 3 stars hotel
   - ☐ 4 stars hotel
   - ☐ 5 stars hotel
5. Which is the usual price range (price per night) of your bookings? *(single choice)*
   - ☐ 0-25 €
   - ☐ 25-50 €
   - ☐ 50-75 €
   - ☐ 75-100 €
   - ☐ 100-150 €
   - ☐ 150-200 €
   - ☐ More than 200 €
   - ☐ I'd prefer not to answer
6. Who are you usually travelling with? *(single choice)*
   - ☐ Alone
   - ☐ With my partner
   - ☐ With my family
   - ☐ With friends
   - ☐ With colleagues
   - ☐ Other: _________

TRAVEL HABITS - environmentally friendly choices

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In the accommodation sector, businesses embracing principles of environmental sustainability are becoming more and more popular.

Some green initiatives promoted by the accommodation are, for instance:

- to propose breakfast with organic or km 0 products;
- to encourage guests to reuse towels,
- to offer environmentally friendly products for toiletries,
- to inform guests about how the energy used by the hotel is produced.

7. When choosing an accommodation, did you ever pay attention to the presence of an environmental policy for the structure?
   - ☐ Yes
   - ☐ No
8. Did you ever stay in accommodation structures that involved you in their green initiatives? *(single choice)*
   - ☐ Never
   - ☐ Rarely
   - ☐ Sometimes
   - ☐ Often
   - ☐ Very often
9. In your view, the presence of an environmental policy in an accommodation structure is: *(single choice)*
   - ☐ A must for the selection of the accommodation
   - ☐ An attribute that could influence the selection of the accommodation
   - ☐ A positive aspect, but it does not influence mu preferences in the selection of the accommodation
   - ☐ An uninfluential aspect for my choice

EXPERIENCES IN HOTELS

The following questions are intended to understand if and how often you experienced unsatisfactory comfort conditions of the accommodation structures you stayed in.

Specifically, the questions focus their attention on personal experiences in relation to:

- noise;
- quality air;
- temperature;
- light;
- natural.

Please answer the following questions thinking back to your stays in accommodation structures during the last year.

EXPERIENCES IN HOTELS – noise

10. How often were you annoyed by external noise? *(single choice)*
    - ☐ Never (skip next question)
    - ☐ Rarely
    - ☐ Sometimes
    - ☐ Often
    - ☐ Very often
11. What kind of noise was it? *(multiple choice allowed)*
    - ☐ Shows or events
    - ☐ Construction sites
    - ☐ Other temporary noisy activities
    - ☐ Transport infrastructures (e.g. traffic, public transport, railway, airport)
    - ☐ Specific noise sources (e.g. bells, alarms, open air activities)
12. What did you usually do to solve the problem? *(multiple choice allowed)*
    - ☐ Nothing
    - ☐ I moved to more silent areas

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- ☐ I wore ear protections
- ☐ I contacted the staff
- ☐ Other: ________

EXPERIENCES IN HOTELS – stale air

13. How often did you perceive stale air in your room? *(single choice)*
    - ☐ Never (skip next question)
    - ☐ Rarely
    - ☐ Sometimes
    - ☐ Often
    - ☐ Very often
14. What did you usually do to solve the problem? *(multiple choice allowed)*
    - ☐ Nothing
    - ☐ I opened the windows
    - ☐ I varied the inlet airflow
    - ☐ I contacted the staff
    - ☐ Other: ________

EXPERIENCES IN HOTELS – temperature

15. How often did you perceive an uncomfortable temperature in your room? *(single choice)*
    - ☐ Never (skip next question)
    - ☐ Rarely
    - ☐ Sometimes
    - ☐ Often
    - ☐ Very often
16. What did you usually do to solve the problem? *(multiple choice allowed)*
    - ☐ Nothing
    - ☐ I modified my clothing level
    - ☐ I modified the thermostat temperature
    - ☐ I opened the windows
    - ☐ I contacted the staff
    - ☐ Other: ________

EXPERIENCES IN HOTELS – natural light

17. How often would you have preferred more natural light in your room? *(single choice)*
    - ☐ Never (skip next question)
    - ☐ Rarely
    - ☐ Sometimes
    - ☐ Often
    - ☐ Very often
18. What did you usually do to solve the problem? *(multiple choice allowed)*
    - ☐ Nothing
    - ☐ I changed the position of blinds (e.g curtains, venetian blinds, external movable shadings)
    - ☐ Switching on the light
    - ☐ Other: ________

EXPERIENCES IN HOTELS – irritations

19. How often did you experience eyes/nose/throat irritations during you stay in an accommodation structure? *(single choice)*
    - ☐ Never
    - ☐ Rarely
    - ☐ Sometimes
    - ☐ Often
    - ☐ Very often

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WILLINGNESS TO PAY

PLEASE READ THE TEXT BELOW THOROUGHLY BEFORE ANSWERING THE FOLLOWING QUESTIONS.

When guests are about to book a hotel stay, relax and comfort are among their main expectations. The factors that contribute to ensure a pleasant stay are various and comfort is undoubtedly included among them. Indeed, the positive effect that a good level of comfort has quality of sleep, stress level, productivity and health it's well recognized. The factors that contribute to guarantee a comfortable indoor environment largely depend on environmental parameters.

In particular, the main requirements to be met are:

• air quality,

• temperature,

• noise level,

• natural light,

• possibility of environmental conditions control.

The continuous maintenance of optimal values of indoor environmental quality at the hotel is a voluntary commitment of the hotelier. It requires high management overhead. These expenses may impact the price of the rooms, in exchange for excellent comfort conditions.

20. Suppose that you are going to spend one night in a double room in a hotel located in Turin Centre at a tariff of 80 €/night. Suppose that the comfort conditions of the guestroom are not satisfactory with reference to air quality, temperature, noise and light. Assume that the payment of an additional amount will help to improve and maintain excellent comfort levels in this room. How much is the maximum additional amount (€/night) that you would be willing to pay in order to enjoy excellent comfort conditions in your room?
    ____

PERSONAL INFORMATION

21. How old are you (years): ________
22. Gender:
    - ☐ Male
    - ☐ Female
23. Nationality: ________
24. City of residence: ________
25. Are you married?
    - ☐ Yes
    - ☐ No
26. Do you have children?
    - ☐ Yes
    - ☐ No
27. Education level: *(single choice)*
    - ☐ Primary school
    - ☐ Secondary school
    - ☐ High school graduate
    - ☐ University degree
    - ☐ Postgraduate degree
28. Job: *(single choice)*
    - ☐ Student
    - ☐ Entrepreneur
    - ☐ Self-employed worker (artisan, merchant, farmer)
    - ☐ Freelance
    - ☐ Executive, supervisory manager
    - ☐ Employee / teacher
    - ☐ Worker / foreman
    - ☐ Belonging to special categories pensioner
    - ☐ Retired
29. Have you ever taken part to any pro-environment non-profit activity?
    - ☐ Yes
    - ☐ No
30. In which range can you insert your monthly gross income? *(single choice)*
    - ☐ Less than 1000 €
    - ☐ 1000-2000 €
    - ☐ 2000-3000 €
    - ☐ 3000-4000 €
    - ☐ More than 4000 €
    - ☐ I'd prefer not to answer

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